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MAY 1941

VOLUME 29 NUMBER 5

Handling Telegrams in Facsimile

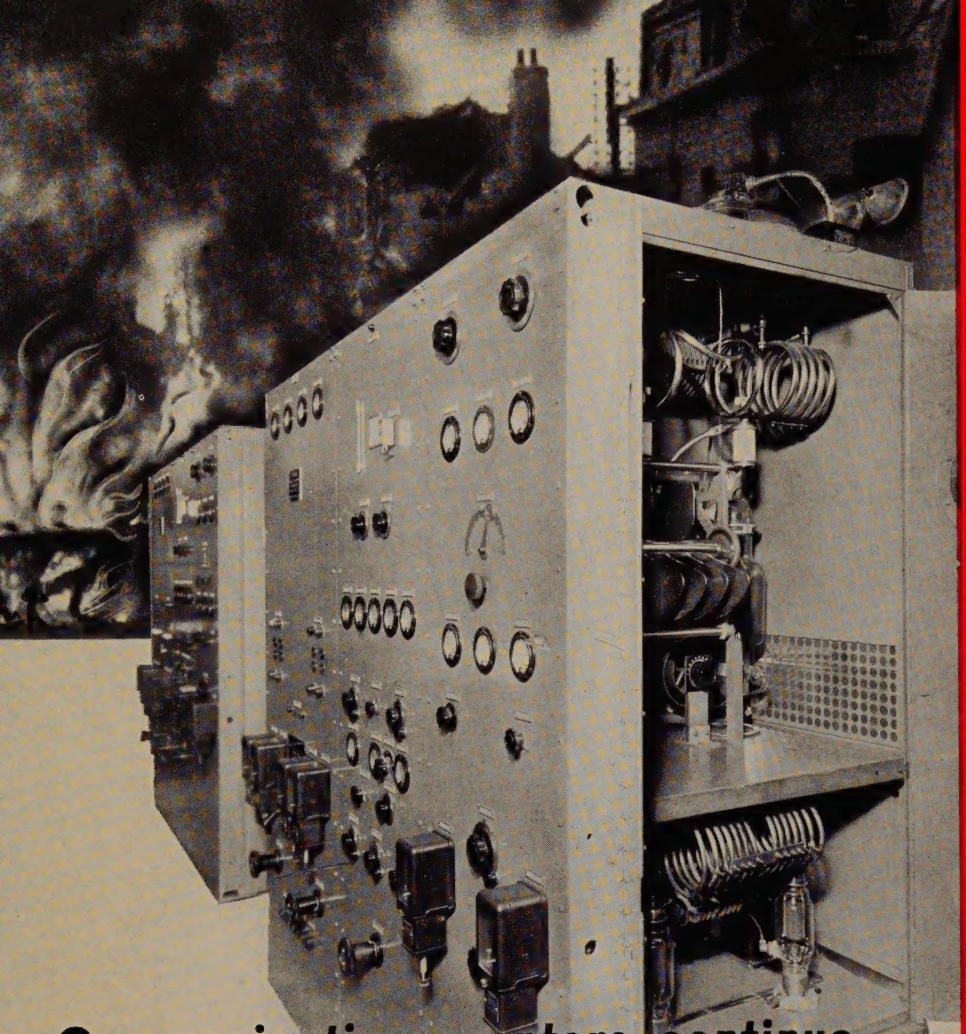
Film Scanner for Television Tests

Multichannel Television Control Equipment

Iron Cores at Radio Frequencies

Undercoupling in Tuned Circuits

Institute of Radio Engineers



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The Handling of Telegrams in Facsimile*

R. J. WISE†, MEMBER, I.R.E., AND I. S. COGGESHALL†, MEMBER, I.R.E.

Summary—*The adaptation of facsimile scanning and recording apparatus to the handling of commercial telegrams has dictated the use of several expedients to accelerate the processing, among them being higher speed of trace and scanning rate, minimization of wasteful scanning, dry-process recording, and automatic loading and discharge. Apparatus incorporating these features is in daily use, having a capacity of 50 telegrams per hour.*

I. Introduction

NO LESS an authority than Guglielmo Marconi, late Fellow of this Institute, is on record[1] as having held the opinion, in 1927, that systems of picture and facsimile transmission, including television, "are most likely to bring to an end the necessity for Morse code signal transmission on which is based telegraphy as we know it today." While the prevalence of Wheatstone transmission in radiotelegraphy and of printer transmission in wire telegraphy might, in 1940, indicate that Marconi was looking far into the future, the laboratories in the meantime have, as a matter of fact, produced apparatus holding promise of giving substance to his vision. Some forms of such equipment have been described in the PROCEEDINGS. Public interest in most of them has been overshadowed by parallel developments of half-tone picture transmission and of television.

In order to determine the optimum rôle of the facsimile process in the handling of commercial telegrams, Western Union has developed various types of facsimile equipment and has used them for several years in the transmission of approximately 300,000 telegrams per annum. In the engineering design of the equipment, the customary endeavor to secure pictorial values associated with the transmission of pictures by photographic technique could be subordinated to securing legible recordings of ordinary typescript at higher scanning speeds. In the handling of telegrams, it seemed fundamental

(1) That the scanning operation at the transmitting end be begun without requiring any special preparation of subject copy.
(2) That the intelligence portion of the message be completely scanned with minimum time wasted in scanning blank paper containing no information.
(3) That scanning proceed at maximum speed measured in linear inches of developed trace per second.
(4) That the scanning structure, measured in lines per inch or pitch of the lead screw, be made optimum to meet requirements of legibility.
(5) That the message blanks, processing fully completed, be discharged from the recording machine immediately upon termination of transmission.
(6) That wasted time be held to a minimum between successive messages, so as not to delay transmission of other unsent traffic.

There were also other desiderata to be satisfied in the actual design, the more important being daylight processing, liberal mechanical tolerances in machining, and interchangeability of scanning and recording machines.

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† The Western Union Telegraph Company, New York, N. Y.

[1] G. Marconi, "Radio communication," Proc. I.R.E. vol. 16, pp. 40–69; January, 1928.

II. Scanning

Reference is made to Fig. 1. A cylindrical scanning drum, 7.76 inches in circumference, (diameter, 2.47 inches), is driven by a synchronous motor at a speed of 180 revolutions per minute, or 3 revolutions per second, developing a peripheral speed of trace of 23.28 inches per second or 1400 inches per minute. A focused light beam from a steady source is reflected from the point of trace back to a photocell for purposes of informational modulation of the transmitting amplifier, but the light beam is mechanically interrupted by a motor-driven toothed "chopper" wheel at the rate of 2500 times a second. This informational photocell, hence, discriminates 2500/23.28, or 107 times per inch of trace, corresponding roughly to a lead-screw progression of 100 lines per inch in the direction perpendicular to the trace. There are thus 10,700 photo-unit areas scanned per square inch.

During the momentary intervals between the 2500 discrete measurements per second which the modulating photocell makes of light reflected from the scanned surface, a second photocell is permitted to become responsive to a beam from an adjustable standard light source optically threaded through the same chopper teeth. The respective outputs of the two photocells can be optically oriented so as to intermesh correctly and feed into an amplifier a 2500-cycle-per-second pulsating current whose amplitude will be governed by the difference in output between the two photocells. In practice the secondary light source, or balancing lamp, is adjusted until the output of its associated photocell is equal to that of the informational photocell when the latter is scanning blank paper. Obviously, if the scanned paper is pink, the balanced, no-current condition will be obtained with a different setting of the balancing lamp than if the scanned paper is white. But if in either case a black pencil mark or other form of intelligence come into the field of scanning, the outputs of the interlaced photocells attain maximum difference, and an alternating current of maximum marking amplitude is borne to line as a 2500-cycle carrier. Minimum informational sidebands would be trans-

mitted if a plain piece of paper were being scanned. The modulating frequency would reach 1250 cycles when the trace passed over an equispaced grid of lines which coincided with alternate photo units.

With a speed of trace of 1400 inches per minute, and an advance of 100 lines per inch, the scanning rate is 14.0 square inches per minute, somewhat higher than any other facsimile or picture system in daily use in this country but not at all crowding the maximum possibilities of the system. At 180 revolutions per minute of the drum, the line progression is 1.8 inches per minute.

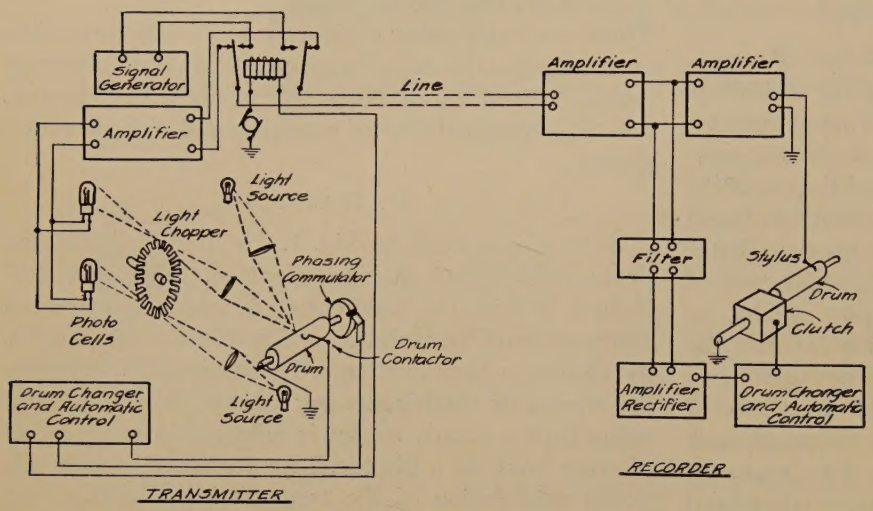

Fig. 1—Trunk circuit facsimile system—schematic.

III. Loading

A standard telegram has a heading 2 inches deep extending across its 8 inches of breadth. The heading, of course, requires no scanning, as its counterpart can be imprinted upon the receiving blanks. The blank to be scanned (and similarly the receiving blank) is wrapped around the drum with its dimension of breadth coinciding with the circular element of the cylinder, thus scanning in a preferred "horizontal" manner the successive lines of typescript which usually constitute the telegram. The blank, when wrapped about the drum, is properly oriented by the operator, both with regard to the position of the heading along the axis and the position of the $\frac{1}{4}$-inch overlap of the blank around the girth of the drum; when correctly "formed," or placed by phasing lines on the cylinder, the blank is held in place by three toroidal spring garters, the middle one of which is free to roll along just ahead of the scanning nose to keep the blank continuously tight against the drum at the point of scanning. Scanning begins at a fixed point just below the heading of the blank, and ends when a point is reached just below the signature on the telegram.

The latter point is fixed by the operator, who, prior to "forming" the blank on the drum, has punched a small hole in the blank at the desired stop point. A feeler, or drum contactor, attached to the scanner carriage, grounds through this hole and starts a train of relays and timed mechanisms to functioning, as the result of which the drum bearing the now completely transmitted message is released from its lathelike stocks, it drops into a hopper, and within 5 seconds has its place taken by another drum bearing another telegram. In the meantime, the scanning carriage has been returned to its initial position just under the heading of the new blank. Simultaneously, a 4000-cycle control tone has been sent to line; upon its arrival at the receiving end it has triggered off an identical chain of events there, and recording of the second telegram begins without delay and without attention. Identical magazines at the two ends hold six loaded drums each, electrically released and gravity fed.

The foregoing sequence can be traced through Fig. 1, from the grounded transmitting drum, through the drum contactor and the drum changer and automatic control, thence through the relay which temporarily substitutes the signal generator to line for the transmitting amplifier. The line tone signal, after passing through the receiving amplifier, is passed by the filter, is rectified, and operates the drum changer and automatic control of the recording apparatus.

IV. Transmission

Ordinary untransposed telegraph lines, worked ground-return, polar duplex, and with applied potentials of 160 volts positive and negative, are suitable for multiplex printer operation but will not transmit the wide facsimile sidebands of 1250 cycles. Such a grounded circuit will satisfactorily handle 225 words per minute in each of the two directions, on 6 printers, all within a band width of 60 cycles per second. The modern tendency, as lines are gradually being paired, transposed, loaded, and equalized, is to provide for an audio-frequency spectrum of 7000 cycles. The two wires of the pair are retained in normal grounded physical two-directional service. Beginning at 400 cycles and continuing by 300-cycle steps upward to 3100 cycles, 10 unidirectional carriers are provided, each of which is capable of carrying the equivalent of a one-way 60-cycle multiplex 3-channel printer circuit. Above 3100 cycles, a choice is afforded either of taking care of 30 more printer channels having a total capacity of 3400 messages per hour, or 1 facsimile channel having a capacity of 50 messages per hour, or 1 telephone voice channel, all unidirectional. If it is desired to place a facsimile circuit at the upper end of the spectrum, the 2500-cycle chopper frequency is doubled by means of a frequency-doubler, and the information

is transmitted on 1250-cycle double sidebands on a 5000-cycle carrier, that is, between 3750 and 6250 cycles.

The amplifier system at the transmitter consists of a photocell preamplifier, and a power amplifier terminating in a line-coupling transformer, furnishing power to line at a level of + 10 decibels based on a reference level of 1 milliwatt. Normal repeater spacing for 20-decibel attenuation is 150 miles, compared with the customary telegraph repeater spacing of more nearly 250 miles.

V. Recording

Synchronization of the receiving drum with the sending drum is achieved by driving the synchronous motors with standard 60-cycle fork-generated impulses, the accuracy of the forks being within 10 parts per million. Combined skew is thereby held to less than $\frac{1}{8}$ inch over the full length of the drum.

Isochronism is obtained through operation of a driving clutch operating in connection with the 4000-cycle drum-discharge line signal and a fixed segment on the drive shaft. Discontinuance of the control tone, which it will be remembered was initiated by a hole punched below the signature of the transmitted telegram, engages the clutch at the recorder and starts in-phase scanning of a new message. In Fig. 1 the operation is indicated by the circuit through the phasing commutator mounted on the transmitting drum shaft, with its definite point of break in the locking circuit; at the recorder, the cessation of the tone signal operates the drum clutch at a point corresponding to the open segment on the phasing commutator of the transmitter.

The incoming signal from the line is amplified and the plate-circuit power, varying between zero and 4 watts, is applied directly to a steel stylus, of slightly less than 0.01 inch diameter, which in the receiving function of the machine, replaces the scanning optical spot of the transmitter. Both stylus and optical systems have considerable mechanical tolerances in "riding" the drums, a valuable feature in making up for unavoidable deterioration in the precision of the machines due to wear.

The recording apparatus just described requires telegram-blank forms to be wrapped by hand around the drums. In a more recent form of recording equipment, this requirement has been obviated by what is, in essence, the interchange of relative movement of drum and stylus. In Fig. 2 is depicted this recorder, wherein the "drum" has become a polished, stationary, vertical cylinder about which the stylus continually revolves in a fixed horizontal plane. The recording paper, which comes in a large roll imprinted as a succession of telegram blanks, is formed as a sheath about the girth of the cylinder as the paper is continuously fed from the bottom of the machine towards the top. The rate of progression, while scanning is taking place, corresponds to that of the lead screw in the transmitter; but, scanning having been completed, the arrival of the control signal causes the paper to move upwards swiftly to a point where the completed message is cut off by a revolving knife and released onto a conveyor belt, ready for distribution. The operation is entirely automatic.

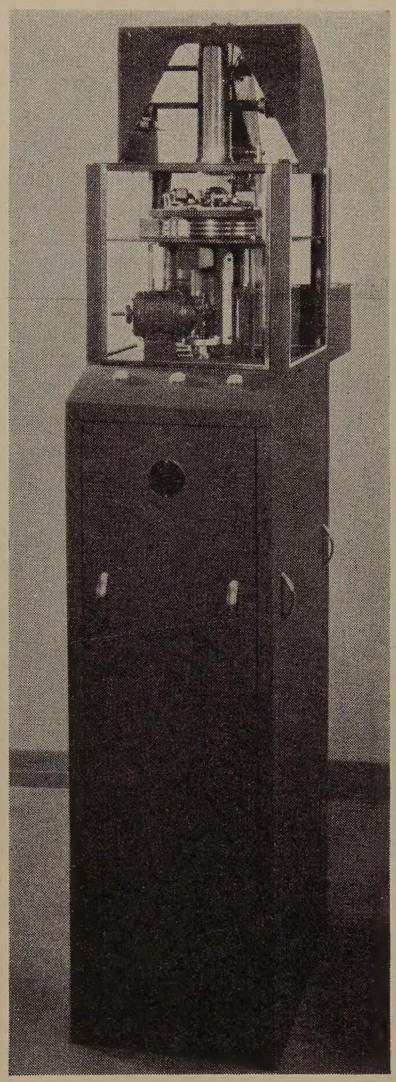

Fig. 2—Continuous-feed stationary-drum recorder.

VI. Paper

The recording blanks are made of conductive, black-backed paper containing carbon, upon which either a vermilion allotropic coating or a gray emulsion, known by the trade name of "teledeltos," has been deposited in layers. A change of background color to black takes place at any point where an electric current passes through the composite sheet. The paper has an impedance of approximately 8000 ohms when scanned with a 0.010-inch stylus under 15 grams pressure and recording 2500-cycle-per-second carrier signals. The resistance of the conducting sheet, as well as the material and thickness of the coating, are under control during the manufacturing process.

The voltage and current requirements are governed largely by the peripheral speed of the stylus, relative to the drum. At 1 inch per second, distinct marking is obtained with 110 volts alternating or direct current applied through a current-limiting resistance of 6000 to 10,000 ohms. At the working peripheral speed of 24 inches per second, the minimum potential is 400 volts and the current through the paper reaches approximately 30 milliamperes to produce marks of maximum contrast. High audio-frequency modulated carrier signals are applied directly to the stylus and paper.

There is no appreciable spreading beyond the physical limits of the stylus. With proper paper speeds, distinct marks representing 0.0001 second can be readily recorded.

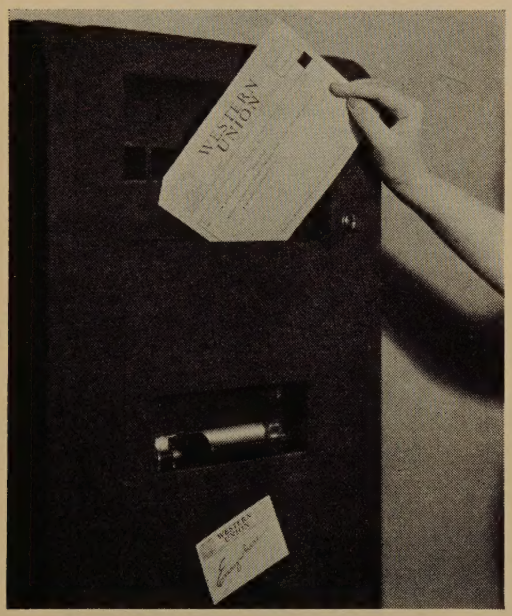

Fig. 3—Slot-fed automatic transmitter—method of operation.

In commercial practice, the light-gray-colored teledeltos paper has a better half-tone characteristic than the allotropic vermilion. For telegrams, both colors have been used with approximately equal fidelity. In order to prevent smudging, the carbon backing is sometimes protected by a silverlike coating. Teledeltos is dry, nonphotographic, and requires no processing, and hence is well adapted to the requirements of telegraphy. Samples exposed daily to bright light and continuously to various atmospheric conditions have shown no evidence of deterioration after several years of exposure.

VII. Applications

The extent to which the use of the facsimile process is expanded in the future will depend upon a number of elements, not all of which can be accurately forecast. Teleprinters of the usual mechanical type are essentially typewriters with added electrical controls, and their cost, in production, is determinable roughly by comparison with electromechanical office machinery. On the other hand, facsimile transmitters and recorders are more like electrically driven phonographs embodying audio-frequency amplifiers. Basically, then, it would appear that the cost level of facsimile units in production is likely to be lower than that of teleprinters, especially in applications where synchronization problems can be eliminated by the use of a single source of alternating-current supply by the machines at the two ends of a circuit. A feature of facsimile which appeals to the operating forces is complete freedom from "typewriter-keyboard" hazards made manifest as letters dropped, added, repeated, and transposed, overtypes, and end-of-line pileups. Since the facsimile process deals with messages, rather than words and letters, as units, a given amount of operating skill and exertion is translated into greater productivity than in the older forms of telegraphy.

On the other hand, there is a natural hesitation to prophesy that definite present-day trends toward printer machine switching, reperforating, varioplexing, and telemetering will be junked over night. Printers transmit intelligence at the rate of 2.5 to 4.0 cycles per letter compared with 73.6 by facsimile. Four printer messages being simultaneously transmitted require a 300-cycle band of carrier transmission, compared with 2500 cycles or more for a single facsimile message. Printers turn out 113 run-of-mine messages per hour compared with 50 on a facsimile machine. Practically every impulse on the line controlling tape printers conveys intelligence, whereas, in contrast, a 335 per cent loading is placed upon page-form facsimile intelligence for the scanning of blank paper. There are also some difficulties to be met in changing from printer to facsimile methods in a telegraph office. The customer does not always file messages a facsimile of which the the telegraph company would be proud to deliver. Soiling and wrinkling of relay copies must be guarded against. Fidelity, unless controlled, may go so far as to furnish addressees with telegrams bearing the thumbprints of operators in distant cities.

VIII. Automatic Telegraph

A balancing of the foregoing points, together with a consideration of frequency spectrum values on long and short lines, has thrown sharp emphasis upon the desirability of using facsimile transmission as a means of connecting branch telegraph offices with main offices, in the larger cities of the United States. In such applications, line costs are of minor consideration; there is available a common source of alternating-current power at the two ends of each circuit; and, due to the comparatively light traffic loading of many branch-office circuits and customers' tie lines, a field for facsimile exists that is being extensively cultivated.

Figs. 3 and 4 show a recent type of facsimile transmitter adapted to mounting upon a wall, counter, or pedestal to facilitate the filing of telegrams by the pub-

lic. The units are provided with either push-button start control for service under clerical supervision, or with key-and-lock control for service in office buildings for charge-account patrons who are supplied with keys. Small glass panels carrying directions for procedure to be followed in transmitting a telegram are built into the face of the cabinet above the message slot, and are successively illuminated by a control switch located at the central office. A number of these transmitters may be connected in multiple to one line. Only one transmitter may be used on the line at a time; when one is in use, "Line Busy" signals appear on all other transmitters on that line and they cannot be started until the line is clear. At the main-office end, a form of circuit concentration is employed which reduces to a practicable figure the number of receivers to be associated with a larger number of circuits and transmitting machines.

Fig. 5 is a schematic diagram of an unattended transmitter, the main-office recorder, and the controls by which the system is manipulated. In this system, where, for simplicity and economy no balancing is employed, an inverted signal is impressed upon the line by direct scanning; at the receiver, an inverter is incorporated in the amplifier unit to convert the signal from its negative to a positive sense. Tone signals representing the facsimile transmission pass over the line pair in the direction towards the main office only; the separate wires of the same pair carry polarized direct-current signals in grounded operation in the opposite direction for the control of the transmitter through the polar relays shown. A multiple-position, 4-level rotary switch is used by the receiving operator to control the functions of transmitting and recording ma-

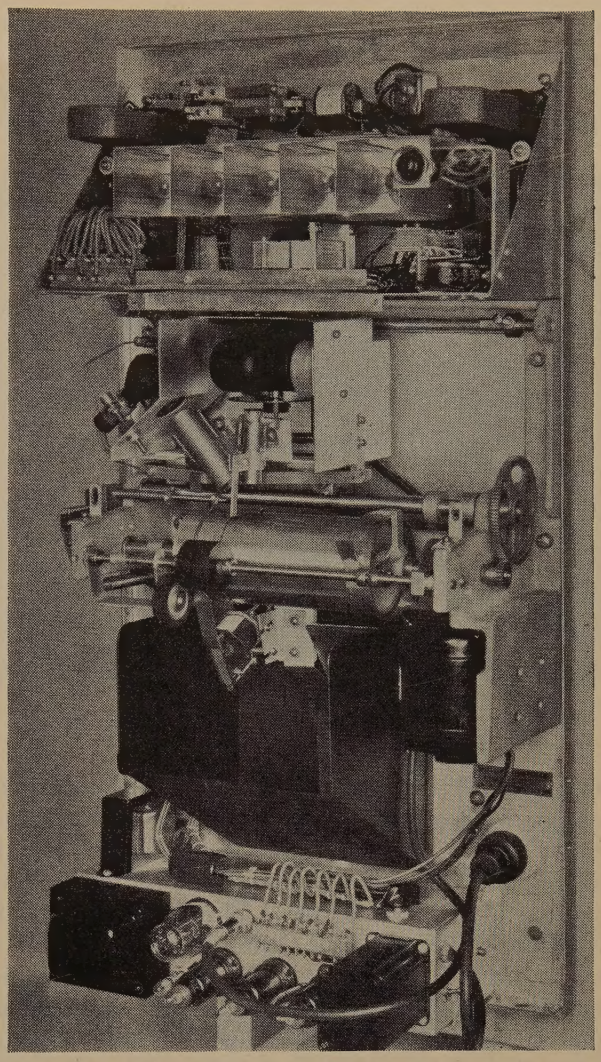

Fig. 4—Slot-fed automatic transmitter—cover removed.

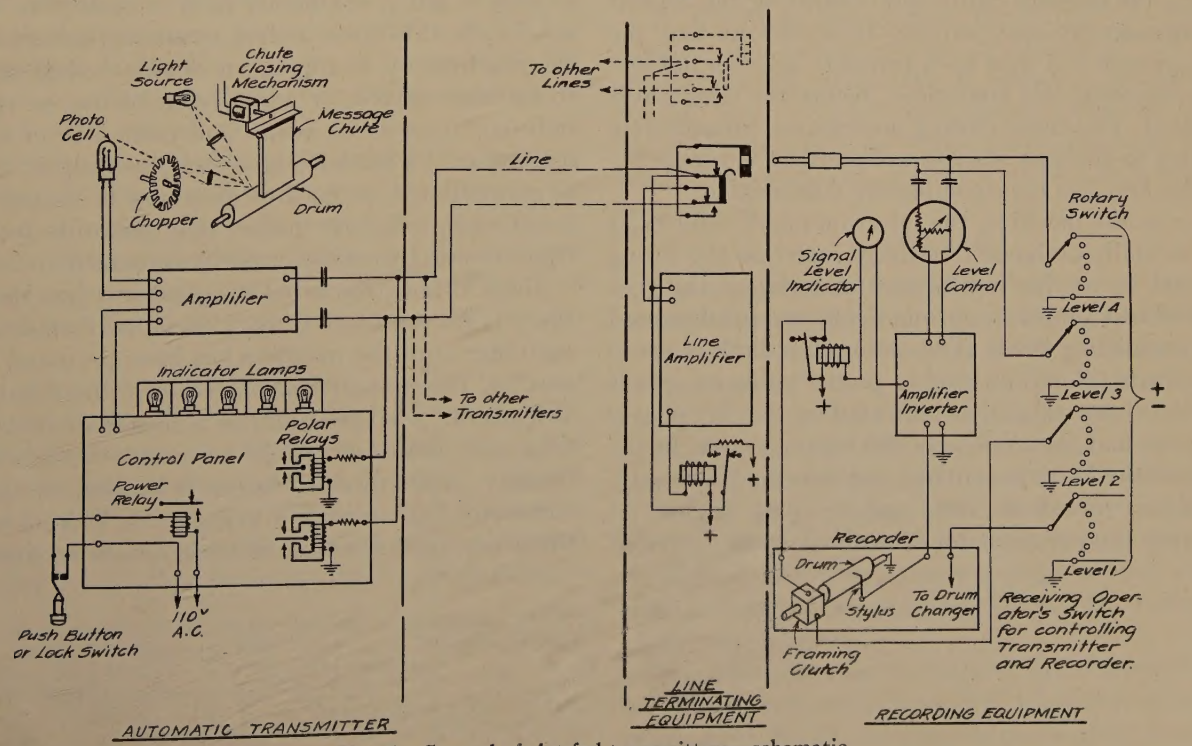

Fig. 5—Control of slot-fed transmitters—schematic.

chines simultaneously and to illuminate the indicator lamps at the transmitter.

The transmitting amplifier remains in operating condition throughout the period that the machine is avail-

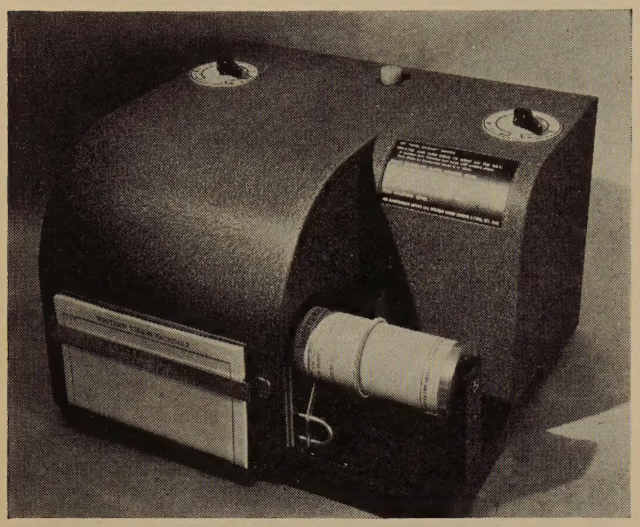

Fig. 6—Customer's drum-type recorder-transmitter.

able for use. When the customer is about to transmit a message he inserts his key and operates the lock switch, which, through the power relay, starts the chopper and drum motors, the lamp, and all other functions of the transmitter. Light reflected from the bare drum causes a carrier signal to be transmitted to the line. Upon its arrival at the line-terminating equipment, it is amplified and locks up a relay which summons an operator by signal and which also causes one of the polar relays at the transmitting office to operate, opening the message chute and permitting the deposit of a message without waiting. It is obvious that the entire system has thus been tested in its essential features, including line conditions, before the telegram is deposited. The chute-closing mechanism immediately operates to prevent insertion of another telegram before the first has been completely transmitted.

Once in the machine, the telegram blank, which has been specially designed to prevent insertion the wrong way and to confine intelligence material to the area that will be scanned, is automatically wrapped around the transmitting drum. The main-office clerk plugs in and adjusts the power level to proper value by means of the level control and as indicated on the signal level indicator, and then operates the rotary switch to the first position. The transmitting and recording drums are thereupon started in phase and scanning begins. At the same time the patron is notified by illuminated panel: "Telegram being transmitted." When the facsimile of the original has been satisfactorily recorded at the main office, a panel reading: "Telegram accepted —Thank you" is lighted, and the original telegram is stripped from its drum. If directions have been disregarded by the sender, or for some other reason an illegible telegram is received, a panel reading: "Rewrite telegram, please" can be lighted. Before asking the customer to rewrite a telegram, the main-office operator is able to control the transmitter so as to effect a rescanning of the telegram either with or without a change in the power level of the signals being recorded.

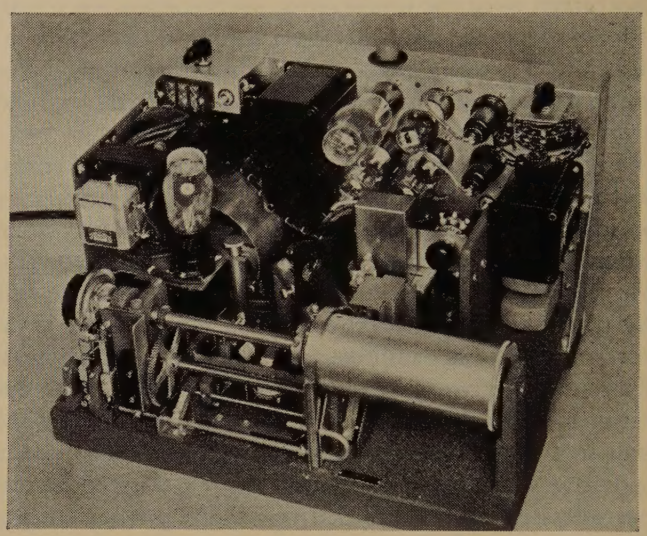

Fig. 7—Customer's recorder-transmitter—cover removed.

Another form of machine subject to concentration at the main-office end is the transmitter recorder shown in Figs. 6 and 7, commonly used in customers' tie-line service. In this form, a clerk or stenographer operates the machine by wrapping an original typed telegram to be transmitted, or a receiving blank, as the case may be, around the drum, and pulls a lever to start operations. "A Send-Receive"switch on top of the unit is manipulated to control direction of transmission; interlocking circuits make manipulation foolproof. Operation is thereafter entirely automatic.

Since in both the types of apparatus just described there is no telegraphic work to be performed by the customer once the machine has been prepared for operation, the system has been called the "Automatic Telegraph." Its extension, as a means of making the telegraph more accessible to users throughout the country, constitutes so far as is known, the greatest commercial advance now being made looking towards the widespread handling of telegrams in facsimile.

Film Scanner for Use in Television Transmission Tests*

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Summary—*This paper describes the design and construction of a television film scanner primarily intended for use as a testing tool in designing circuits suitable for television program transmission.*

The equipment employs electronic scanning and the image dissector is used as the electronic pickup device. The image dissector has a high degree of linearity between light input and signal output and the picture signal is not accompanied by any spurious shading signals. Furthermore, the direct-current component of the television signal is directly available at the output of the tube. The lower sensitivity of the dissector tube is not important in this case since a highly efficient optical projection system makes it possible to override noise to a high degree.

In film scanners for entertainment purposes it is desirable to use ordinary 24-frame motion pictures and such film scanners therefore include a mechanical or optical translating mechanism for translating the 24-frame film picture into a 30-frame interlaced television picture. In the present equipment it was found more expedient to simplify the construction by allowing the use of specially printed film. Ordinary 24-frame film is "stretched" by printing every other frame twice and the remaining frames three times in succession, thereby producing a film with a total of 60 frames instead of the original 24. Vertical scanning is then obtained by the continuous motion of this film at the rate of 60 frames per second and horizontal scanning by a simple electronic line sweep in the dissector tube.

Introduction

DURING the past ten years or so the requirements for satisfactory transmission of television signals have become steadily more and more severe, and for successful reproduction of present-day television pictures of 441 lines, interlaced, and 30 complete frames per second it is now necessary to provide for the faithful transmission of electrical signals occupying a total band width of several megacycles. The problem of connecting outlying pickup points with the main television broadcast transmitters and of interconnecting such transmitters through a long-distance television program network has therefore resulted in the development of broad-band wire transmission circuits suitable for the transmission of high-definition television signals.

The transmission problems involved in the design of such wire circuits have recently been described in another paper[1] which clearly illustrates that the requirements imposed on television circuits are quite different from and in some respects much more severe than those involved in broad-band, multichannel telephone circuits.

This is partly explained by the peculiar transient character of television signals and partly by the fact that the mechanism of the eye in translating visual impressions into nerve responses is totally different from that of the response of the ear to sound pressure. Thus the ear is very sensitive to harmonic distortion caused by overloading, but quite insensitive to changes in the phase relations of the harmonic components in an audio-frequency note. On the other hand a sharp pulse in a television signal may be flattened somewhat by overloading without disturbing the eye very much, but any shift in the relative phase of the harmonics of this pulse is easily detected as a change in the wave shape.

It is quite obvious therefore that one useful method for determining the requirements involved in television transmission and for investigating the behavior of television wire circuits is the television signal itself, and moreover a television signal of such a high quality that any distortions introduced by the transmission medium are not obscured by residual errors in the original signal. In evaluating the factors influencing the design of a generator capable of producing such television test signals the following considerations prove to be of primary importance:

1. Wide range of contrast.
2. High degree of linearity between incident light flux and electrical output voltage.
3. High signal-to-noise ratio.
4. Effective frequency band of at least 4 megacycles.
5. Absence of phase distortion.

Of these, item 5 may be disregarded in the choice of the generator itself since it is largely a function of the electrical circuits associated with the generator.

To the items listed above there might be added a further requirement of ease of operation and maintenance, which will make it instantly available for routine tests. This last requirement rules out the use of a mechanical scanner which might otherwise be considered as capable of satisfying items 1 to 4 to a very high degree.

General

The choice, therefore, is limited to an electronic scanner of some sort and of the tubes available for the purpose at the time this equipment was designed the image-dissector tube appeared to fulfill all the requirements. It is true that this type of pickup tube is not as sensitive as certain other camera tubes, but we are here interested only in the scanning of motion-picture film and not in direct pickup, and it is possible therefore by using an efficient optical projection system to increase the light flux on the cathode to such a point that the noise is determined mainly by shot noise inherent in the photoemission itself.

The dissector has the further advantage of being quite free from spurious signals, while the relation between light flux on the photocathode and voltage out-

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[1] M. E. Strieby and C. L. Weis, "Some factors affecting television transmission," PROC. I.R.E., vol. 28, pp. 533–534; November, 1940. (Summary only.)

put of the multiplier is entirely linear. The type of tube used was designed especially for film scanning and obtained from the Farnsworth Television & Radio Corporation.

The mode of operation of the dissector tube is well known and will be described here only very briefly. Fig. 1 shows a cross-sectional view of the tube with its associated focusing and sweep coils. By means of the

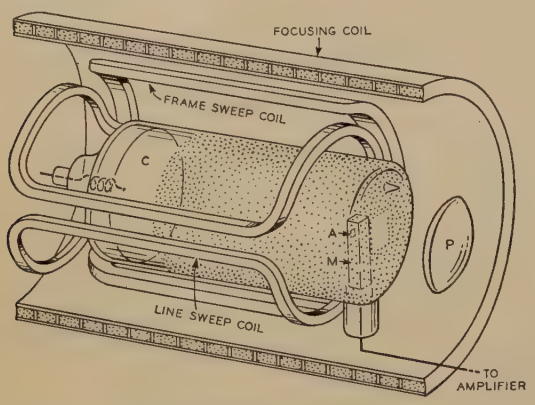

Fig. 1—Skeletonized view of image dissector, focusing coils, and sweep coils.

projection lens P an optical image of the film is formed on the cesium-silver-oxide photocathode C. Saturated photoemission is obtained from this cathode by means of a positive potential of about 300 volts between the cathode and the nickel anode covering the inside cylindrical wall of the tube. A solenoidal field from the focusing coil brings the photoelectrons to a focus in the plane of the multiplier aperture A, thus forming an electron image of the object in this plane. Finally the horizontal and vertical sweep coils produce saw-tooth-shaped magnetic fields which serve to sweep the entire electron image in front of the multiplier, thereby allowing successive elements of the image to pass through the aperture and thence through the multiplier and from there to the first stage of the video-frequency amplifier.

It will be seen from this, that if standard motion-picture film is passed by continuous motion in front of the lens at the rate of 24 frames per second and if the electron image is swept horizontally past the multiplier aperture at the rate of 24×441 times per second, the vertical sweep being disconnected, then the signal at the output of the tube will correspond to a television picture of 24 frames and 441 lines, sequential scanning.

In order to obtain a television picture of 30 frames and 441 lines interlaced from standard 24-frame film it would be necessary either to employ an extremely quick-acting intermittent film motion, which would impose an excessive mechanical strain on the film, or else to incorporate some rotating or vibrating parts in the projection system, such as for instance described in a recent paper by Goldmark.[2]

In the present film scanner this problem was solved by reprinting standard film so that frame No. 1 is printed twice in succession, frame No. 2 three times, frame No. 3 twice, frame No. 4 three times and so on. In this way the original 24-frame film is "stretched" into a 60-frame film, and passing this new film through the machine at the rate of 60 frames per second and scanning horizontally at the rate of 30×441 times per second the output signal produced will correspond to a television picture of 30 frames and 441 lines interlaced.

The cost and inconvenience of using specially printed film probably would prove prohibitive in a film scanner to be used for entertainment purposes, due to the large number of films of constantly changing subject matter which would be required. In the present laboratory scanner, on the other hand, it is sufficient to choose a small number of representative film subjects, and it was felt that the cost of having these reprinted was more than outweighed by the resulting simplicity and ease of maintenance of the mechanical and optical system.

In the foregoing it has been assumed that no vertical sweep is used, but actually a small amount of 60-cycle vertical saw-tooth sweep is applied for the following two reasons.

In standard motion-picture film the space between successive frames amounts to about 15 per cent of the total frame interval, while in present-day television the time allotted to vertical blanking is about 7 per cent. Thus a television picture of nominally 441 lines would actually show about 410 lines during direct pickup and only about 380 lines when obtained from a film scanner, as described above, without vertical scanning. By applying a vertical scan of 8 per cent of the frame height in the direction of the film motion it is thus possible to regain 30 lines which would otherwise be lost due to the width of the frame spacing.

This small amount of vertical scanning also results in another and even more important advantage. If no vertical sweep is employed the same part of the photocathode is used over and over again for all the lines of the picture and unavoidable minute irregularities in the surface and photosensitivity of the cathode will show up as faint vertical streaks in the picture, of very much the same character as those obtained in the optical projection of an old and scratched film. By employing a small amount of vertical scanning the scanned line on the photocathode is shifted continuously at the rate of 60 times a second, with the result that these vertical streaks disappear entirely.

Mechanical Construction

The mechanical and optical arrangements employed are seen in Figs. 2, 3, and 4, Fig. 2 showing a close-up photograph of the film-moving mechanism. The film

[2] P. C. Goldmark, "A continuous type television film scanner," *Jour. Soc. Mot. Pic. Eng.*, vol. 33, pp. 18–25; July, 1939.

drive consists of a converted Western Electric sound-recording unit geared up to run at the rate of 60 frames per second instead of the usual 24. As will be seen in Fig. 2, the film enters from the reel housing and passes over the driving sprocket at the right. This sprocket takes the load of pulling the film from the reel and feeds it to the main sprocket at the left. The latter is driven through a high-grade mechanical filter, and short loops of film are left between the sprockets in threading so as not to interfere with the action of the filter or tear the film. After projection the film passes over the lower part of the driving sprocket and thence to the lower

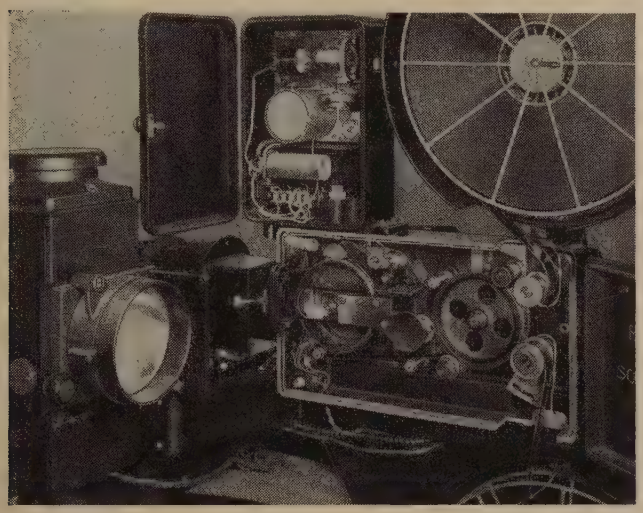

Fig. 2—Close-up of film mechanism.

take-up reel. The filter is on the other side of the housing and does not show in the photograph.

The main sprocket wheel is mounted overhanging on the shaft and the cylindrical surface is cut away to permit passage of light through the film frame leaving only supporting bars for the outer rim of the same width as the space between successive frames.

The light housing is hinged on one side and when the machine is working the door is closed, the light housing is swung in front of the door and the light passes through a hole in the door, through the right-angle prism shown in the photograph in Fig. 2, and from there through the film and the projection lens into the dissector.

The light source is a 1000-watt projection lamp fed from 110 volts alternating current and controlled by a Variac. The lens is a good quality camera lens of 6-inch focal length and aperture $f/1.9$. At full aperture of the lens the visual focus does not quite coincide with the photoelectric focus, due to the high infrared sensitivity of the cathode surface, but the difference is very slight and vanishes completely at an aperture of $f/4$. Focusing is accomplished by remote control from the monitoring position by means of a Selsyn motor. The light and the aperture are adjusted so as to give a total cathode current of about 200 microamperes for clear film.

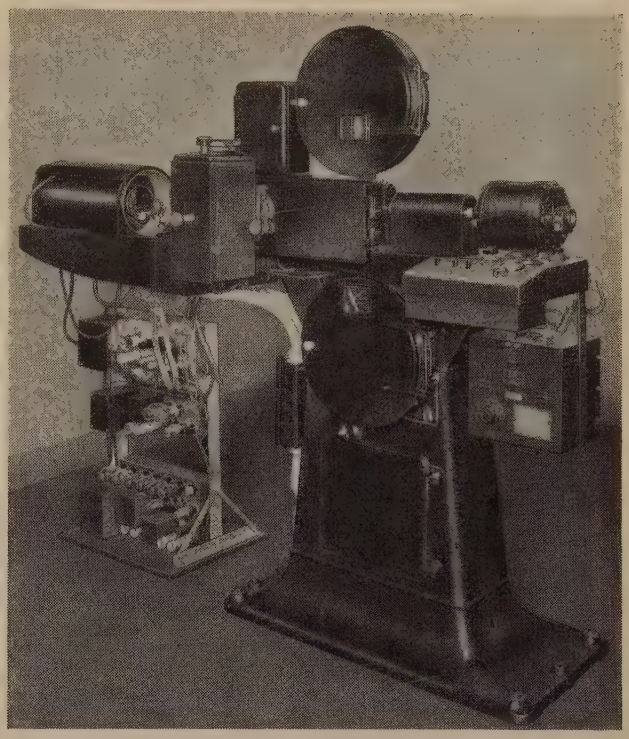

Fig. 3—Film machine and dissector.

Provisions are made for inserting a slide with a single film frame in front of the main sprocket wheel. The optical focus is changed slightly in this case and it is necessary now to use a full-amplitude vertical sweep. In this way the machine may be used also for scanning "still" pictures of test patterns, etc.

Arrangements have been made also for picking off the sound from a sound track recorded on the film in the ordinary manner. For this purpose the film passes over a bridge shown directly above the main sprocket wheel and by an arrangement of prisms, light is made to pass through the sound track and up into the photocell shown in the small housing on top. The actual arrangements will be understood better by referring to Fig. 5, which shows a vertical cross section through the main sprocket wheel and the sound bridge.

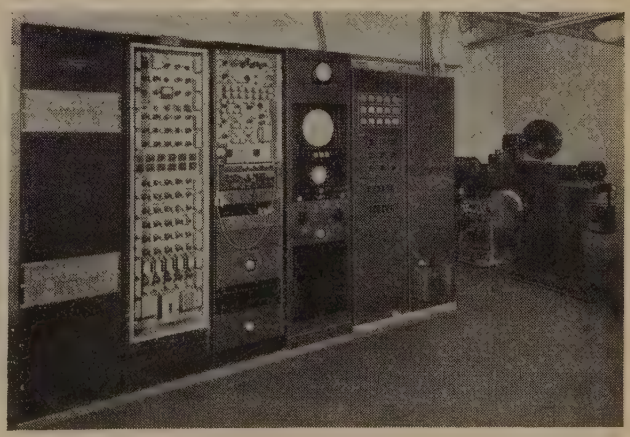

Fig. 4—Complete film transmitter.

Focusing System

In order to discuss the distortions present in the electron-optical focusing system of the dissector let us first

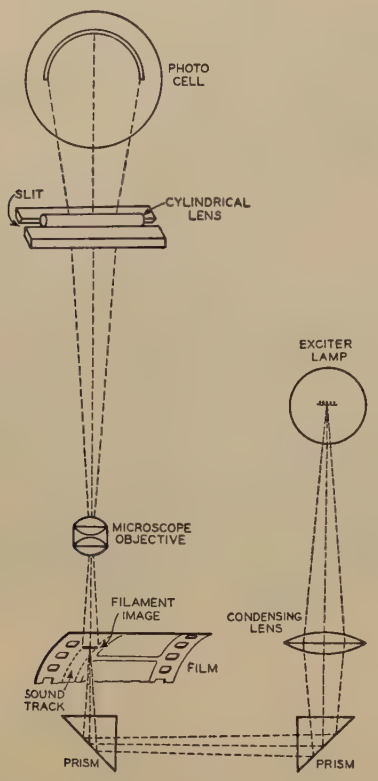

Fig. 5—Schematic view of sound optical system.

consider a simple theoretical case in which all electrons leave the cathode with the same velocity in the direction of the axis and pass into the anode cylinder through a perfectly uniform magnetic field parallel to this axis. In this case an undistorted, upright electron image of magnification 1:1 would be formed in some plane parallel to the cathode. In practice such a condition may be reached approximately by the use of a solenoidal focusing coil long with respect to the distance from cathode to multiplier and of large diameter with respect to the picture size.

Another way of obtaining 1:1 magnification would be to employ a very short focusing coil placed halfway between the multiplier and cathode, but in this case the image would be inverted. If this short coil is moved towards the cathode the magnification increases and conversely the image size will decrease if the coil is moved towards the multiplier. At the same time the radial component of the magnetic field will cause the electron image to be rotated a certain number of degrees with respect to the image on the cathode, the amount of rotation depending on the relative distance of the coil from the cathode and the multiplier, respectively, and the direction of rotation depending on the direction of current in the coil.

Since the radial component of the field increases with the distance from the axis the angle of rotation of the image will also increase with this distance, thereby causing straight lines across the original picture to exhibit a certain amount of objectionable S distortion in the reproduced electron image. The obvious way to avoid this distortion would be to employ two identical short coils wound in opposite directions and placed symmetrically with respect to the mid-point between cathode and multiplier but, while such a coil system would compensate for rotational distortion it would at the same time tend to increase other types of electron-optical aberrations such as "pincushion" or "barrel" distortion and spherical aberration.

In practice the matter is further complicated by the fact that the photoelectrons do not all leave the cathode with the same velocity. The geometrical configuration of the cathode and the anode in the dissector are such that the electric accelerating field extends somewhat into the anode cylinder while the theory above assumes an accelerating potential applied between the cathode and a plane parallel to the cathode and immediately in front of it, with no electric field present inside the anode cylinder. The actual accelerating field between the cathode and anode will cause all electrons to enter the anode cylinder with substantially the same axial velocity but with additional small radial velocities directed away from the axis. The final method adopted to overcome rotational distortion was therefore to use a so-called tapered coil as shown schematically in Fig. 6. The purpose of this coil is to produce a magnetic field of such a configuration that the magnetic lines of force approximately

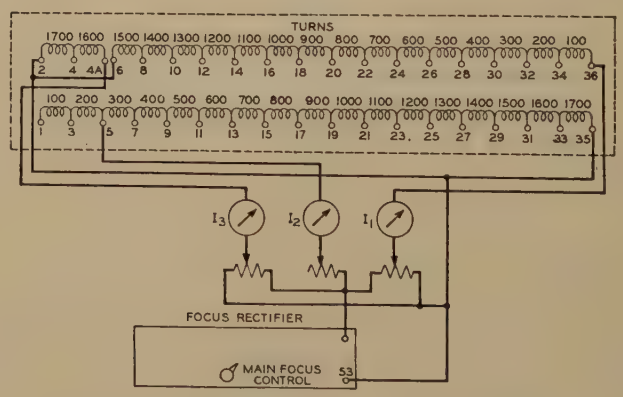

Fig. 6—Circuit diagram of tapered focusing field.

coincide with the electron trajectories. In this case no transverse magnetic force is exerted upon the electrons and therefore no rotation takes place. Furthermore, a coil of this type will permit easy adjustment of the magnification within reasonable limits.

The coil has two windings wound on top of each other, each consisting of 17 sections spaced equidistant along the length of the coil and wound with an increasing number of turns from one end to the other. The inner, main winding is wound with 1700 turns in the first section nearest the cathode and gradually decreas-

ing to 100 turns in the last section nearest the multiplier, while the outer, adjusting winding is wound with 100 turns in the first section, increasing to 1700 turns in the last section. By adjusting the relative magnitude of the main current I_1 and the adjusting current I_2 it is thus possible to vary the effective taper of the field, and thereby the magnification, without affecting the focus.

The first two sections of the main winding are energized separately by the current I_3 in order to effect an end correction for counteracting the end effect of the coil and maintaining a linearly tapered field right out to the plane of the cathode.

The distortions discussed above may be conveniently examined by the use of a "dummy" dissector tube in which the multiplier is removed and the end of the tube coated with fluorescent material. The cathode is ruled with horizontal and vertical lines and flooded with infrared light and by focusing on the end of the tube a visible electron-optical image is attained on the fluorescent screen.

Fig. 7 shows photographs of pictures obtained in this way with three different types of focusing coil. At the left is shown the effect of using a short focusing coil near the cathode. The approximate field distribution is indicated by iron filings in the upper part of the figure and the photograph below shows the partly rotated electron image with pronounced S distortion. Furthermore, lines near the edge of the screen give distinct indications of pincushion distortion. In the center of the figure similar pictures are shown for a tapered coil without end correction. The rotation and S distortion is less than before, but still noticeable, and pincushion distortion is still present. Finally, the right part of the figure gives the result of applying a strong end correction near the cathode end of a tapered coil. The picture is now practically upright and free of distortions.

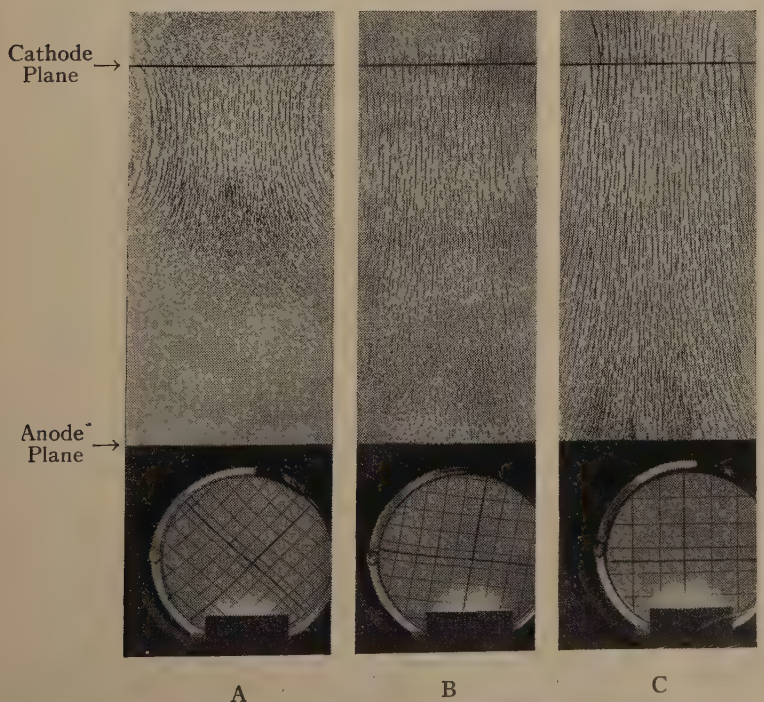

Fig. 7—Focusing fields and S distortion.

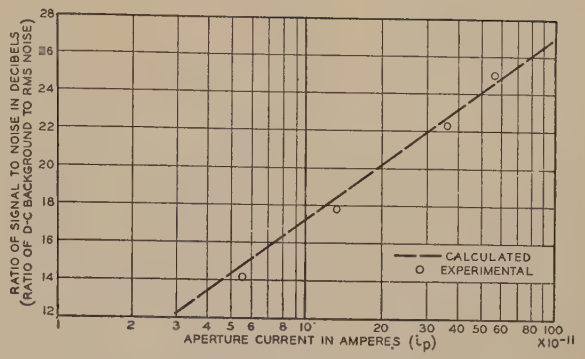

Fig. 8—Signal-to-noise ratio versus aperture current in dissector.

Signal-to-Noise Ratio

The amount of light available from the projection system is sufficient to produce at the cathode the maximum brightness allowable without danger of surface deterioration and under these conditions the cathode image should be made as large as possible in order to increase the signal-to-noise ratio. On the other hand, too large an image will result in edge distortion due to nonlinearity of the sweeps and nonuniformity of the focusing field. When a suitable compromise has been found the electron-optical magnification is determined by the size of the multiplier scanning aperture. Too large a magnification will result in underscanning the picture and also in the same edge distortions mentioned above, while too small a magnification will result in overlapping of consecutive lines with resulting loss of detail.

The size of the motion-picture-film frame is 0.848×0.636 inch; the optical magnification is approximately 3.5 times and the electron-optical magnification 1.32 times, thus giving an electron image of 3.86×2.97 inches. This will give correct scanning with a multiplier aperture of 7.5 mils and consequently the aperture chosen for the first tube was 7.5×7.5 mils. Later it was found advantageous to increase this aperture to 9×12 mils since the slight overlapping of scanning lines thus encountered was more than outweighed by the increased signal-to-noise ratio.

For a dissector tube with an aperture of nominally 7.5×7.5 mils the signal-to-noise ratio was determined experimentally under the following operating conditions:

Area of light image on cathode
5.8 square inches

Area of electron image at plane of aperture
10.1 square inches

Area of multiplier aperture
56.2×10^{-6} square inch

Average cathode sensitivity
35.7 milliamperes per lumen
Average multiplication
153,000

Noise measurements were made with a current analyzer at different light intensities and at different frequencies and indicated uniform distribution of noise with frequency. The results are given in Fig. 8 as signal-to-noise ratios expressed in terms of direct-current background signal and root-mean-square noise for a band width of 4 megacycles.

The dotted line is the calculated shot noise, chiefly that due to photoemission, and the circles are measured points. The curve shows the usual square-root relation between noise and signal and the agreement with the measured points indicate the absence of any other type of noise. With an aperture of 9×12 mils the signal-to-noise ratio should be about 3 decibels higher.

Sweep Circuits

The problem of obtaining linear sweep fields for the dissector is more difficult than for most other types of camera tubes, because of the large volume over which a uniform sweep field must be maintained. The requirements are particularly severe for the line sweep where the high value of the fundamental frequency makes it difficult to obtain a sufficient number of ampere turns without increasing the inductance and distributed capacitance to a point where the self-resonance of the coil will seriously affect the linearity of sweep.

When using coils with a concentrated winding, i.e., coils producing substantially the same field distribution as a single turn of wire, it has been found that the

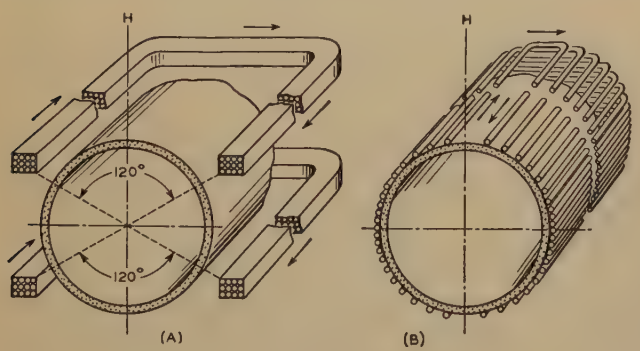

Fig. 9
(A) 120-degree concentrated-winding sweep coil.
(B) Sweep coil with cosinusoidal current distribution.

best approximation to a uniform transverse field inside a cylinder is obtained by placing two coils on opposite sides of the cylinder, each coil subtending an angle at the cylinder axis of 120 degrees and the coils connected so that their fields add. A cross-sectional view of such an arrangement is shown in Fig. 9(A).

A much higher degree of field uniformity is attained if the wires in the coil are distributed over the entire cylindrical surface in such a way that the current density along the periphery varies as the cosine of the angle measured from the edge of the coil. A cross-sectional view of such a coil system is shown in Fig. 9(B). If the cylinder is infinitely long and the current distribution exactly cosinusoidal such an arrangement will produce a transverse field which is absolutely uniform over the entire volume of the cylinder. In practice the finite number of turns produce slight field irregularities near the cylinder wall and the finite length of the coil causes some nonuniformity near the end due to the bunched end turns.

The power required to produce a certain field intensity at the axis of the cylinder is considerably less for this type of distributed coil than for a concentrated coil, and furthermore the lower distributed capacitance of the distributed coil makes it easier to maintain linearity of sweep, for the reasons mentioned above.[3]

The actual coil used for the line sweep is made up of a total of 64 turns or 128 wires distributed around the cylinder as indicated in Fig. 9(B). The wires are laced to the surface of a thin Micarta tube fitting snugly over the dissector tube and the length of the coil is such as to extend somewhat beyond both the cathode and the multiplier of the tube. The inductance is approximately 1 millihenry and the maximum current necessary for the sweep about $\frac{1}{3}$ ampere, thus requiring a peak power of about 15 or 20 volt-amperes for driving the coil.

The saw-tooth current is obtained from a more or less conventional sweep generator of the multivibrator type, controlled by the line pulses from a standard synchronizing generator, and the output from this sweep generator is fed to a three-stage resistance-coupled amplifier with the output stage consisting of three RCA 807 tubes in parallel. The plates of these tubes are connected to an output transformer, the secondary of which feeds directly into the sweep coil through a 72-ohm transmission line.

The sweep coil for the vertical sweep is also designed with approximately cosinusoidal current distribution along the periphery of the cylinder. Due to the much larger number of turns in this coil the wires are arranged in concentrated bunches and these bunches distributed around the cylinder in cosinusoidal fashion with eight bunches in each quadrant. The large number of turns in the frame-sweep coil makes the problem of adequate sweep power very much simpler than in the case of the line sweep and the coil is fed directly from the output stage of the frame-sweep generator. The generator itself is of conventional design and is controlled from frame pulses obtained from the synchronizing generator. The system is provided with a reversing switch and an amplitude control for providing either a normal vertical sweep of full amplitude for use in scanning a stationary film frame or a reversed

[3] The power requirement is further reduced by the use of only 300 volts anode potential, which is somewhat less than the potential normally used in dissector tubes.

sweep of small amplitude for use when scanning a continuously moving motion-picture film.

Blanking and Synchronizing

Before the synchronizing pulses are added to the video-frequency output from the dissector it is necessary of course to establish correct black level, and for this purpose the dissector has an advantage over most other camera tubes in that the direct-current background information is directly available at the output of the multiplier. If direct-current information is obtained at this point, however, it is necessary first to compensate for the so-called "dark current" in the multiplier. This current amounts to about 2 or 3 microamperes in an ordinary multiplier and is caused by leakage and thermionic emission inside the multiplier. This dark current may vary somewhat with time and temperature and since the direct-current signal current proper ranges from $\frac{1}{4}$ to $\frac{1}{2}$ microampere in the black to 40 to 50 microamperes in the high lights it is seen that some uncertainty is present in the black-level information obtained at this point.

Another and more direct method was resorted to, therefore, consisting in applying blanking at the photocathode. It was mentioned above that the cathode-anode potential employed in the dissector is kept down to 300 volts in order to decrease the power requirement for the high-frequency sweep. This low potential is of advantage also when applying blanking in this way since it is necessary to apply to the cathode a blanking-pulse voltage at least equal to the cathode-anode potential. In this way complete suppression of photoemission is effected during the blanking interval and a true black level thus obtained. The dark-current component of the output is now of no importance since all direct-current is blocked by the video-frequency amplifier following the dissector output.

Synchronizing pulses are added to the signal in the usual manner in the latter part of the video-frequency amplifier chain and the signal finally emerges at the line amplifier output as a 441-line 30-frame interlaced television signal with an amplitude of 2 to 4 peak volts into 72 ohms. The synchronizing pulses are supplied from the same synchronizing generator that supplies the pulses for the dissector sweeps and blanking, and this generator is, of course, locked in with the same power supply as that used for driving the film-moving mechanism.

Other Equipment

The synchronizing generator is a standard RCA rack-mounted studio generator and may be seen in the second rack from the left in Fig. 4. The third rack shown in Fig. 4 consists of RCA video-frequency amplifiers and associated equipment, the fourth rack is the main monitoring position incorporating an RCA monitoring receiver and oscilloscope, and the last two racks contain all of the equipment for driving the dissector tube.

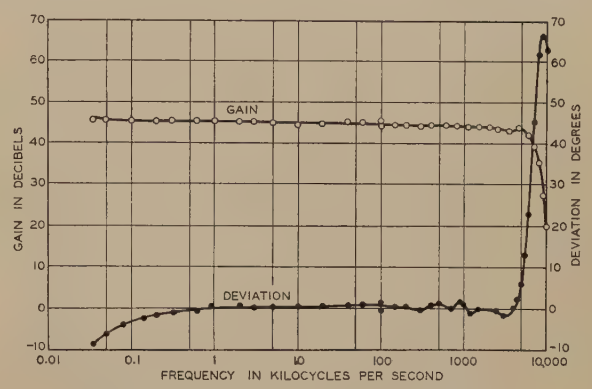

Fig. 10—Over-all gain and phase deviation versus frequency.

The video-frequency amplifiers were originally designed for use with an iconoscope camera tube and have been modified somewhat to fit their use with a dissector tube. Measurements of the complete amplifier chain from dissector output to line input show substantially flat gain and reasonably low phase distortion up to 4 megacycles or more, as may be seen from Fig. 10, which shows the measured amplitude and phase characteristics as a function of frequency. These measurements do not include a separate, equalizing network inserted to correct for the usual aperture distortion introduced by the finite size of the multiplier aperture.

Versatile Multichannel Television Control Equipment*

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Summary—*The production of high-definition television programs has necessitated the development of equipment which is particularly adapted to both the technical requirements of the system and the operating requirements of program presentation.*

This paper describes control-room apparatus which is suited to modern television program technique by its flexibility, ease of control, and dependability. The division and grouping of the operating controls and indicators are such as to co-ordinate the action of the several operators effectively, yet providing for a wide variety of effects and precision of control. Provision is made for switching cameras into and out of the line, fading up or down, and lap-dissolving any two channels in any order or type of change-over desired.

The circuits used and the arrangement of equipment within the control room are such that the expansion of facilities (such as addition of new channels) can be accomplished without disturbing existing equipment. Improvement of program service by such expansion is expected in most installations because the initial equipment must be simplified as far as possible and yet be capable of continuous use at peak performance.

Interesting features of the many components of a complete studio control setup are pointed out and described briefly. These include the pulse generator, video-frequency amplifiers, camera sweeps, channel and line monitors, picture-quality controls, control console, cue equipment, and audio-frequency equipment.

Introduction

THE ABILITY of a television system to accomplish a pleasing presentation of entertainment material depends to a great extent on the variety of pictorial and audible effects which can be utilized to create necessary illusions of continuity and realism in a television receiver.

It has been found that high picture quality *per se* is not enough to insure success in the transmission of television entertainment that can be valued for more than its sheer novelty. Programs must be good, smoothly run, and transmitted with an interesting variety of wide-angle and close-up views. Aside from the program material itself, factors entering into an entertainment medium such as television broadcasting must be considered by the engineer and the equipment designed in such a manner that it can be used effectively in program production. Many of the problems associated with this phase of television are similar to those in the motion-picture industry, and established methods of picture production furnish a good guide in planning a television service.

It must be remembered that the television control room is analogous to the darkrooms and cutting rooms which play an important part in motion-picture production. Moreover, passage of the program through the control room is accomplished with the speed of light, a discomforting thought for the prospective producer. The facilities in the control room must be sufficiently complete that an entire production may be carried through to its conclusion without hesitation or obvious imperfection. Since there can be no "retakes," every function which is important in a production must be made as simple as possible, and each member of the personnel must thoroughly understand his part as well as its relationship to all other operations.

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General Considerations

Studio control equipment has the important job of satisfying both the operating requirements of program technique and the technical requirements of the particular television system in use. Early experience at W2XB[1] showed that the facilities must be "geared" for program production, but that picture quality should not be sacrificed in any way in the effort to simplify operations.

It should be possible to choose one or two of several views of a subject in the studio so that the action or story can be televised effectively. Accordingly, it should be possible to accomplish the transition between various views or scenes in any possible order or combination of switching, fading, or lap-dissolve effects to follow the program material in a pleasing way. The instantaneous nature of television makes it necessary to provide multiple-channel equipment in order to accomplish these bare essentials of production.

The requirements of studio control facilities from an operational point of view can be listed as follows:

A. Picture

1. Multiple-channel equipment including motion-picture pickup apparatus.
2. Adequate monitoring equipment.
3. Means for switching, fading, and dissolving.
4. Supervisory equipment—indicators, studio address, camera direction, picture-quality control, telephone, etc.
5. Simplified operation.
6. Space and facilities for program director.
7. View into studio from control room.
8. Provision for expansion of facilities.

B. Sound

1. Multiple-channel equipment.
2. Adequate monitoring equipment, aural and visual.
3. Supervisory equipment.
4. Cue equipment.
5. Transcription equipment.
6. View into studio.
7. View of picture monitors.

Each installation will be governed somewhat by local conditions, and there will be many additional items of varying importance in most cases.

Although no fixed pattern of program production can be specified, the equipment and its layout in the

[1] General Electric Company, Schenectady, N. Y.

control room should be made with a definite production method as a guide. Because of the necessarily complex nature of the television method of broadcasting, a high degree of co-ordination between the persons and equipment involved in the process is required. Rehearsal still remains as one of the most effective means of attaining this important result, but design of the equipment for convenience and comfort of the operators brings its dividends in the form of better entertainment value due to smooth technical performance. Awkward motions must be minimized, for operators who are concentrating on their own movements in an effort to "pull the show through" are quite likely to miss important cues or otherwise lower the quality of their performance.

In general, it is normal for a program director to work in the control room where a view of the outputs of the several cameras as well as the studio itself can be had. It is to be expected that there may be several directors, each associated with a different production, with the possibility that none of them is trained in the operation of the major controls of the system. The controls that are made available to the program director should, therefore, be made extremely simple and their number kept small. The will of the director is exercised by verbal messages to the operators in the control room and the studio during rehearsal and by verbal cues and final script in the control room during a broadcast.

Because of their greater familiarity with and better access to the controls, the operators generally take over the major portion of technical direction after sufficient rehearsal has been had to establish the desired routine. Good direction and ample technical facilities for direction are necessary to promote the teamwork required of the operating staff. Studio programs usually require a large rehearsal-to-program-time ratio, and it is during rehearsal that the equipment receives its greatest use. It is important, then, that the design of the equipment be extended to allow efficient use for rehearsals as well as during programs. Frequently, it is necessary to carry the rehearsal of certain parts of a program up to program time, or perhaps to make last-minute setups of a scene during the transmission of another. Under these and similar conditions, multiple-channel picture, sound, and supervisory facilities are of unquestioned value.

Very few television studios will begin their operations with really elaborate installations. It is highly desirable to allow space in the control room for the addition of new equipment when the need for more complete facilities must be met. In most cases, however, continuity of service must be maintained, or at least the interruption of an established schedule by expansion of program service in this manner should be as slight as possible. The electrical system used in the initial equipment should, therefore, be planned carefully, so that the addition of more channels will not require temporary shutdown of all transmissions. The equipment in all channels should be as nearly identical both mechanically and electrically as possible. This allows substitution in case of failure of any unit and simplifies maintenance of the system.

Control-Room Design

It is important that the control room used in television broadcasting provide sufficient space for the personnel as well as the equipment necessary for operation. It is equally important, too, that the layout of the equipment be planned carefully so that a certain unity is preserved in the interest of smooth and efficient handling of the equipment. A practical limit to the number of video channels associated with one control room is six, most studios requiring a maximum of three or perhaps four in even the most complex type of program. Of course, the initial layout of the control room should be such as to accommodate the maximum number of channels expected in the future.

Another requirement of the control room is that it be located advantageously with respect to the studio and be provided with a large window which permits an unobstructed view from the operating positions into practically any part of the studio. The control room should be located at the end of a rectangular studio at a height with respect to the studio that will prevent obstructions such as persons or scenery "flats" from interfering with the view through the window into the studio. It is during rehearsal that this window will be of greatest value, since the positions of the studio equipment and sets are determined jointly by the studio personnel and the control-room staff in this period. The problem of maintaining low light levels in a control room which overlooks a brightly illuminated studio has been solved by applying a covering of 30-mil "Plastacele"[2] to the control-room side of the window. It is impossible to see into the darkened control room from the studio with this covering in place, but no advantage would be had if it were possible to do so. The window should be designed for high acoustical attenuation, as is normal practice in broadcast studio design.

A system of monitoring each channel output continuously on a monitor associated permanently with the same channel has been adopted at W2XB. In addition to monitors for each channel, there is provided a line monitor which shows the composite outgoing picture. Directly in front of each channel monitor is a group of controls affecting only that channel. These controls are referred to as "quality" controls, since they provide control over shading, brightness, electrical camera focus, and similar parameters which affect picture quality directly.

The monitors and associated quality controls are built into a monitor console which is placed just below the window between the studio and control room. The

[2] A DuPont product.

monitors are tilted upward in such a manner that they are visible to the program director and operators who are seated at a program console elevated about 18 inches from the level of the monitor console. The men at the program console are able to look into the studio or directly at the monitors over the head of an operator

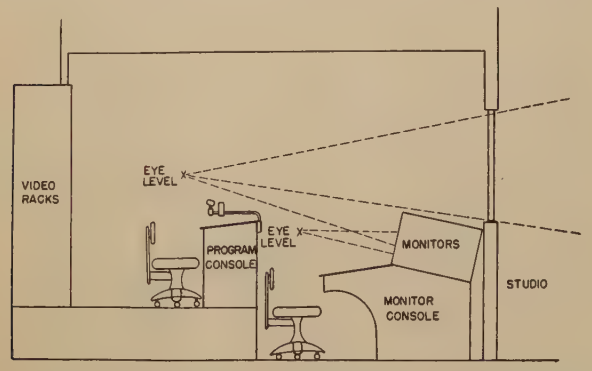

Fig. 1—Elevation of control room. Operators at program console have unrestricted view into the studio and of the monitors.

who presides over the console containing the monitors and channel quality controls. The position of this operator relative to these monitors is such that he is able to judge picture quality critically and thus determine the nature and amount of adjustment each channel should receive. Plan and elevation views of this arrangement are shown in Figs. 1 and 2.

The equipment associated with the several channels is located at the rear of the control room in a series of vertical racks. This equipment requires initial or setup

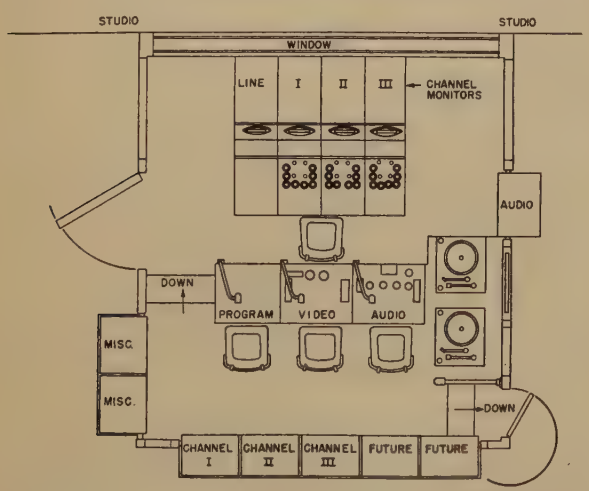

Fig. 2—Plan view of control room. Sufficient space is provided for increasing the number of channels to five.

adjustment only, but is located in the control room so that the monitors can be used in checking these adjustments. Fig. 1 shows that there is a one-to-one correspondence between the rack-mounted equipment and the channel monitors, and that ample space is provided for two additional channels including monitors.

Transcription equipment is located to the right of the program console where it may be used by the audio operator from his position at the controls of the audio system. A rack similar to those housing video equipment is used for mounting low-level audio equipment in a region reasonably free from strong magnetic fields. A monitor speaker is mounted on the wall above the studio window.

From their positions at the program console the program director and the two operators are enabled to direct all phases of a program. Each can see all the monitors and hear the sound as well as see into the studio when it becomes necessary. The controls centralized at the video position allow the video operator to give warning signals, and switch, fade, or dissolve from one channel to another. The controls available to the audio operator allow associated effects to be produced with the accompanying sound. Should it become necessary at any time, the video operator can make adjustments on the equipment behind him or can issue verbal instructions to the operator seated at the monitor console. With a control setup of the kind described, each man has definite responsibilities, and the workings of the group as a whole are co-ordinated effectively.

Monitor Console

An important part of the control system is contained in the monitor console. This console is built in sections so arranged that additional sections can be added when the number of channels is increased. The monitors themselves are contained in rectangular boxes 15 inches wide, 18 inches high, and 28 inches long which

Fig. 3—Television-studio control room. View of monitor console showing video operator's position.

slide into guides provided in the framework of the console assembly. Electrical connections are made by means of plugs which are inserted into the bottom of each monitor. These plugs serve also as safety interlocks, since it is necessary to remove them before sliding a monitor out of the console. Channel "quality" controls are located on sloping panels in front of each channel monitor, providing valuable association of control and monitoring facilities.

Each monitor unit contains a 12-inch diameter white-screen picture tube and a 3-inch diameter wave-

form monitor. Monitor controls appearing on the sloping front panel allow independent control of picture and wave-form monitor parameters such as brightness, contrast, size, centering, etc. Figs. 3 and 4 show the monitor console in use at W2XB.

Video signals from the channel amplifiers are fed to their respective monitors over concentric lines at a 1-volt peak-to-peak level. Separate amplifiers within the monitor unit serve to apply amplified video signals to the vertical deflection plates of the wave-form monitor and to the control grid of the picture tube. Gain controls in each amplifier allow the signals to be varied without transient from zero to more than enough to obtain satisfactory operation of the two cathode-ray tubes when the input signal is at normal level. The output circuits of the amplifiers are arranged to provide for reinsertion of the direct-current component of the signals, so that one calibration of the wave-form monitor may be made to serve for picture signals representing any average brightness. Fixed horizontal sweep frequencies of either 30 cycles or 4410 cycles may be applied to the wave-form oscilloscope by means of a switch on the front panel of each monitor. These are, respectively, $\frac{1}{2}$ field frequency and $\frac{1}{3}$ line frequency in a 441 odd-line interlace system operating at 30 frames per second. Horizontal and vertical sweeps for the picture monitor are contained in each unit. All sweeps in the monitor console are synchronized from separate line- and field-frequency synchronizing busses which also synchronize other units of the control apparatus.

The monitors are marked plainly by large annunci-

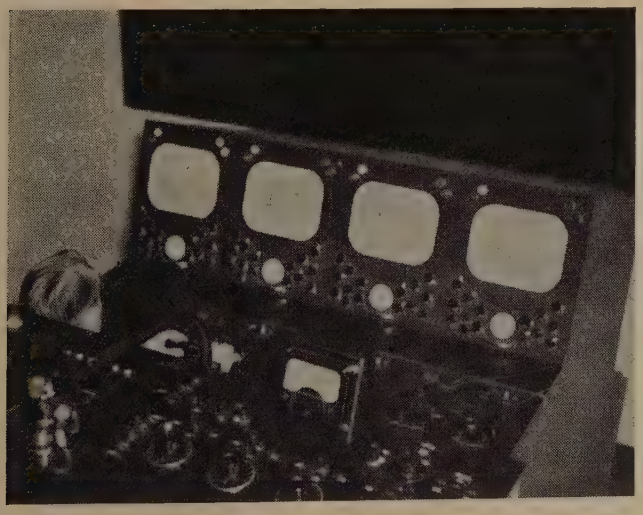

Fig. 4—Television-studio control room. View of monitor console from audio operator's position.

ator-type illuminated numbers which correspond with the channel designations. In addition, green warning or "preview" lights and red "on-line" lights are provided on each channel monitor. The line monitor is provided with illuminated numbers which are in parallel with the red "on-line" lights of the corresponding channel monitors. The close grouping of the picture, wave form, and indicators at the line monitor concentrates essential program-monitoring functions into a small area which is situated advantageously in the control system.

The channel quality controls located on a hinged panel in front of each channel monitor are arranged so

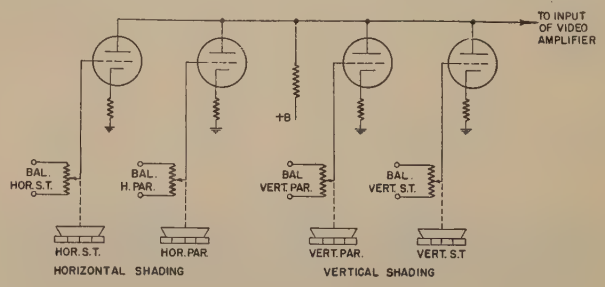

Fig. 5—Simplified diagram of shading control. Potentiometers control the magnitude and polarity of signals fed to the mixing tubes.

that adjustments necessary to maintain high picture quality are made as simple and complete as possible. Ample blank space is provided ahead of the group of controls to enable an operator to attain a comfortable and convenient position of his forearms and to allow cue sheets to lie flat in such a manner that they may be read conveniently. Large skirted knobs are used on controls that require more or less constant attention, while small pointer-type knobs are used on the controls which require only occasional adjustment.

The parameters affecting picture quality directly may vary somewhat depending on the type of camera tube used. There is general agreement, however, that any type of camera tube must be provided with a means for setting electrical focus, scanning current, and horizontal and vertical centering. One popular type of camera tube requires horizontal and vertical shading controls and a "bias-light" control in addition to control of these fundamental adjustments. Other channel quality controls include "contrast" and manual background (or "black-level") controls. These two controls affect the gain and direct-current insertion, respectively, in the video amplifier circuits. An "off-on" switch controls the application of beam-accelerating voltage to the camera tube, so that the remainder of the channel may be operated without reference to conditions at the camera tube. Safety interlocks remove high voltage from the under side of the hinged panel when it is raised, and disconnect the output of that channel from the studio output circuits.

The shading system used affords great simplicity and smoothness of control. Two basic wave forms are used to permit compensation of spurious camera-tube signals. Varying amounts of these two wave forms are required at horizontal (line) and vertical (field) scanning frequencies under different conditions of lighting, beam current, and subject matter. Frequently, one or more of the compensating signals must be reversed in polarity to obtain good results. The need for simple and unambiguous control action under these conditions led

to the installation of a balanced-shading-control method shown in Fig. 5. Each of the four control potentiometers is fed with a signal of the desired wave form whose voltage is balanced with respect to ground. Thus, the voltage applied to the shading mixer tube from each control can be made to vary smoothly from maximum of one polarity through zero to maximum of the opposite polarity. It has been found that operators can master the controls quickly, since a certain direction of rotation has always the same compensating action regardless of its initial position.

Fig. 6—Television-studio control room. Audio operator, video operator, and program director at their console.

The saw-tooth and double-parabola waves used for compensation affect the edges and the center of the picture, respectively, the field-frequency waves affecting the top and bottom edges and "vertical" center of the picture, the line-frequency waves affecting the left and right edges and "horizontal" center of the picture. The arrangement of the controls on the panel is made consistent with the effects of the controls by placing the two parabola-wave controls in the center of a line of four controls, flanking them by their respective saw-tooth controls as shown in Fig. 5. The polarity of the signals applied to the controls is made so that a given direction of rotation of knobs controlling waves of the same form but of different frequency produces a similar appearance on the wave-form monitor and in the picture. Another psychological effect of control unity is obtained in these controls by making clockwise rotation of the "parabola" knobs cause increased brightness in the center of the picture and a clockwise rotation of the horizontal "saw-tooth" knob to cause increased brightness on the left edge of the picture. Ordinarily both hands are used in manipulating the controls, the left hand controlling the line-frequency signals, and the right hand controlling the field-frequency signals. The arrangement of the knobs is made in two groups such that the same fingers of the respective hands have similar effects on the picture, except, of course, that these effects are evidenced in the horizontal direction for left-hand actions and in the vertical direction for right-hand actions.

The shading compensation voltages are mixed in the common plate circuit of the four tubes of Fig. 5, and the resulting composite wave form is applied to the input of the video amplifier system. These mixer tubes and a line-matching system for each channel are located in small chassis containing the shading controls. These chassis are mounted on the under side of the hinged panels of the monitor console in such a position that the shafts of the controls extend through the panels to receive the control knobs.

The position of the operator seated at the monitor console affords no direct view into the studio. Instead, it substitutes a convenient view of the channel picture monitor tubes at a viewing distance that allows critical appraisal of picture quality. Together with the location of the associated wave-form monitors and the channel quality controls, this arrangement permits effective emphasis to be placed on picture quality without sacrificing utility for program use.

Program Console

The three operators of the program console are seated side by side with the video operator at the center section of the console, the program director at his left, and the audio operator at his right (see Fig. 6). The requirements of the program director can be expressed orally, both during rehearsals and transmissions, and the two technicians will then give the necessary instructions or perform the indicated operations. A complete system of communication is provided, enabling these operators to contact any of the supporting staff in the studio or film pickup booth. Signal lights supplement direct communication by indicating to cameramen and control-room operators which picture channels are available, on the air, or about to be used. Mechanically, the program console provides for the comfort and convenience of the operators. The sloping top is regular table height, and the controls are all moved forward to leave 12 inches of space for notes and elbowroom on the part of the console nearest the operators.

The video section of the program console is designed to handle as many as six camera channels. This number was selected as a maximum, because it appeared adequate for any single control-room system having, for example, one production studio, a small interview studio, and a film pickup booth. A larger installation would best comprise a master control room with separate control equipment for individual studios.

The block diagram of Fig. 7 shows the arrangement of video circuits through the program console. The switching and fading equipment is inserted between the channel amplifiers, where zero output current represents black, and the line amplifier. Thus, any underlap in switching transmits a black signal upon which the synchronizing pulses (added in the line

amplifier) can ride without noticing a momentary lack of true pedestals. The switching circuits connect between the 75-ohm lines to the channel monitors and the faders, which are simple 500-ohm linear potentiometers. Their outputs are mixed electronically at the console in a small mixing amplifier whose output goes to the line monitor and the line amplifier.

The video section of the program console contains the means for switching, fading, or lap-dissolving between any two of the six picture channels. Switching is accomplished by means of low-capacitance video relays located in the console, and are controlled by push buttons on the top of the console. There are two sets of six relays, each set capable of connecting any one of the six channels to one of the two fader potentiometers (see Fig. 7). Each set of relays is interlocked electrically so that no channel can be selected on both sets at the same time. Pressing a particular push button causes its relay to pick up and hold in. Simultaneously, any other closed relay in that set drops out.

The fader potentiometers are mechanically interlocked so that if one is fully in, the other is entirely out. Also, raising one to maximum output simultaneously reduces the other to zero. If, for instance, a particular channel is feeding through the left bank of relays to fader *A*, and it is desired to fade down to black and up on another channel, the new channel is preset on the right bank by pushing the proper button. At the chosen time, fader *A* is reduced, and fader *B* may be

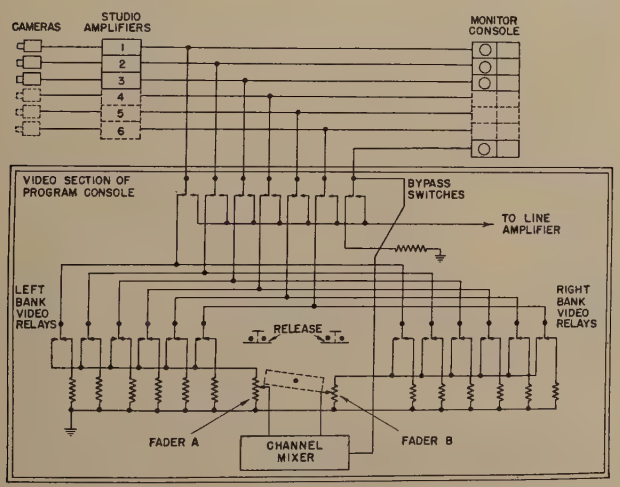

Fig. 7—Line diagram of video circuits through program console. By-pass switches allow any channel to be omitted from the switching and fading circuits and connected directly to the line amplifier.

advanced after the first has been brought to zero. An alternative method which does not require a preset is to fade the outgoing channel down to zero, pick up the desired channel on the same bank of relays, and fade up the new one on the same control. To accomplish a lap-dissolve under the same circumstances, the same preset is made and then the right fader is turned up. This reduces the left fader at the same rate, making the old picture dissolve into the new one. Quick switching is accomplished by pushing the desired button associated with the same set of relays that is feeding the signal at the time. The results of these operations are illustrated in Fig. 8. A release button in each bank of relays allows cancellation of presets when necessary.

The switching relays have additional contacts for interlocks and for switching signal lights. Every channel which is operating has an "available" light showing

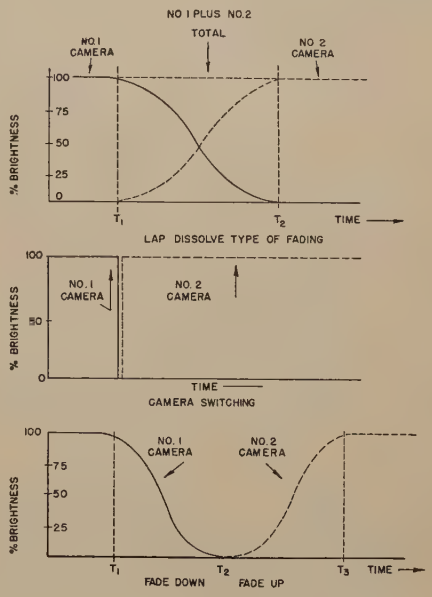

Fig. 8—Graphic representation of the three fundamental types of channel change-over. In the case of a lap-dissolve, the combined peak signal is never greater than the peak signal of the larger of the two channels involved. Combinations of these three types of change-over may be formed by the operator who can determine the rate, type, and sequence of the changes.

above its push-button control. When a channel is switched to the line, the "available" lights go out and "on-line" lights appear above its push button, on its monitor, and on the camera supplying it. Sometimes it is desirable to give a visual indication of which camera is the next to be put on the line. Therefore, a set of six "preview" relays, push-button-controlled, is provided on the video section of the program console. These operate green lights on the cameras, on the monitors, and at the switching push buttons on the console. The relays are interlocked with the switching relays so that throwing a previewed channel on the line, automatically drops out the preview signals. Although the "preview" system need not be employed, its use helps operators and performers to prepare for the incoming channel.

Fig. 7 shows also the connection of a set of seven "by-pass" switches. By closing any one of the first six by-passes, the corresponding channel may be fed directly to the line amplifier without passing through the switching and fading system. The seventh switch connects the mixer output and line monitor to the line amplifier. By means of the by-passes, any channel (supplying a test pattern, perhaps) can feed the transmitter, leaving the remainder of the control-room

equipment to function unimpaired for rehearsals and auditions.

The program director's section is equipped with only a studio-address microphone and switch and a telephone handset. This leaves the top of the desk clear so that notes may be made or read conveniently.

The audio control system is connected as a modified single channel, making possible almost complete dual-channel operation. This was necessary to meet the condition of film or other transmission during rehearsal or audition (see Fig. 9). There are four microphone chan-

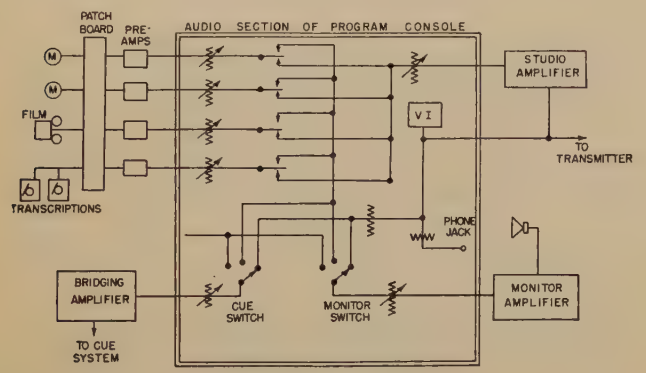

Fig. 9—Line diagram of dual-purpose audio control system. The double-throw switches allow any input signal to be connected to the program line or to an audition bus. The monitor amplifier and the "cue" bridging amplifier may be connected either to the program line, the audition bus, or an external source (not shown).

nels: one for transcriptions, one for film pickup, and two for studio use. Any input channel may be switched to either a program bus or an audition bus. The program bus is energized by the studio amplifier, whose output feeds the transmitter, and may be monitored conventionally through the monitor amplifier and speaker. The monitor amplifier has enough gain, however, to permit monitoring rehearsals from the audition bus directly, while other audio signals, which may be monitored elsewhere in addition, are fed through the studio amplifier to the transmitter. An external connection is made through a bridging amplifier, so that the program output, the audition output, or any external signal source (such as another program) can be supplied to the studio through the cue system to be described later.

Conventional audio control equipment is mounted on the audio section of the program console. There are four microphone-channel attenuators, and attenuators for the studio and monitor amplifiers. Output level is indicated by the new type of standardized volume indicator, with an illuminated scale for easy reading in the darkened control room. A telephone jack is provided on the console top for monitoring the output to the line during transmission while the monitor speaker is used for audition.

Effective co-ordination among all the persons in the studio and control room depends on getting instructions to the proper places quickly and without interference to those not concerned. It has been found that both one-way and two-way communication are necessary. The control-room personnel must be able to give cues and instructions to the studio by means of a loud speaker during rehearsals and to the cameramen, light operators, and microphone boom men (who wear headphones) during transmissions. Two-way telephone service to the studio, to dressing rooms, and to the film pickup booth are equally important.

The program console is equipped to provide adequate communication facilities for all three of the program operators (Fig. 10). At each position there is a microphone supported conveniently in talking position, and a handset mounted near it, both well clear of the controls on the console top. The selector switches for the microphone (cue system) are located for operation with the left hand. The selector switches for the telephones are located at the right of each operator.

The program-director's section has only one selector switch. It is used for connecting the program director's microphone to the studio talk-back speaker, for direct instruction of players during rehearsals. The telephone at this position connects only to a station in the studio convenient to the assistant director or stage manager. The telephone hook switch automatically makes the connections when the handset is lifted.

The video section has cue system connections to speakers in the studio and in the film pickup booth, and to headphones for three cameramen, and two light operators. There are telephone connections to the studio, the film pickup booth, and the dressing rooms.

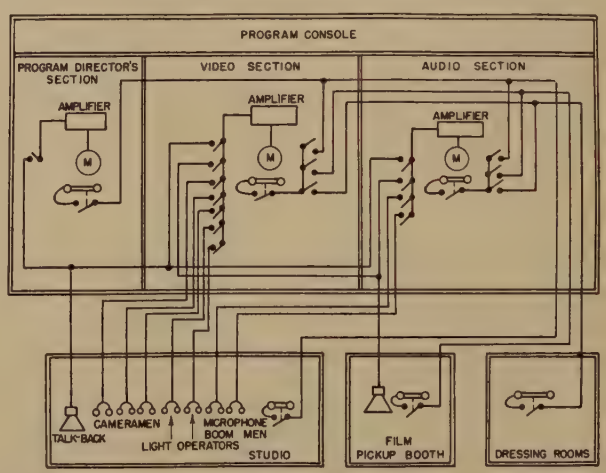

Fig. 10—Line diagram of studio communication system. The switches at each section of the program console allow great flexibility in the interconnection of the various stations.

The audio section has cue-system connections to speakers in the studio and the film pickup booth, and to headphones for two microphone boom men. It has telephone connections to the studio, the film pickup booth, and the dressing rooms.

One or more of the selector switches for both the cue system and the telephone system may be locked in at will by each operator, to allow instructions to several points simultaneously. The line diagram shows how the

program director's instruments may be connected to any point in the system through the video and audio operator's selector switches. Signal lights are provided on the video and audio sections of the console to indicate when the common communication channels are available. Each microphone feeds into the cue system at the output of its own amplifier, at 5 ohms impedance, thus giving proper volume on either speakers or headphones. The studio speaker may be connected by means of a selector switch to receive either the cue-system output or the output of the dual audio system. During transmission from the studio, this speaker may be switched out completely to avoid accidental interference from the cue system.

Video-Frequency Equipment

Before considering a complete multiple-channel installation, an understanding of the process of picture-signal formation in a single channel is required. A simplified block diagram of a single-channel studio installation is shown in Fig. 11. Since picture signals are produced on a strict time schedule, the dependence of all the apparatus on a precise timing device is quite natural. The synchronizing pulse generator (item 6 of Fig. 11) provides all the essential timing waves and other related waves which are necessary in the synthesis of a complete standard television signal.

Other functions which enter into picture-signal formation are performed by:

1. A camera, which includes a camera tube, deflection coils, a picture-signal (video) amplifier, blanking injector, means of producing an image on the sensitive area of the camera tube, a shield against light and electrical interference, and means such as a cable to connect the camera with the remainder of the apparatus.
2. A channel video amplifier.
3. Horizontal and vertical deflection circuits for the camera.
4. A monitor, which includes means for viewing both the voltage wave form of the video signal and the picture.
5. A shading control.
7. A line amplifier and synchronizing mixer.
8. A power supply system.
9. A communication system.

The individual units of Fig. 11 are numbered to correspond with the above listing and the flow of the signals is indicated in order to aid in understanding the diagram more fully. The picture signal is generated in the camera by causing an electron beam produced in the neck of the camera tube to scan a photoelectric mosaic upon which an optical image of the subject is focused. Waves generated by the horizontal and vertical sweep generator feed the deflection coils in the camera with currents which cause the electron beam in the camera tube to scan the desired pattern on the mosaic. It is necessary to extinguish (blank) this electron beam during its retrace across the mosaic in order to prevent discharge of part of the electrical image accumulated by the tiny condensers of which the mosaic is comprised. The small voltage generated by the scanning action is amplified in the camera by a "head" amplifier before it is sent over the cable to the control room. Shading compensation is introduced at the input of the head amplifier so that the possibility of amplifier overload by uncompensated shading signals is reduced.

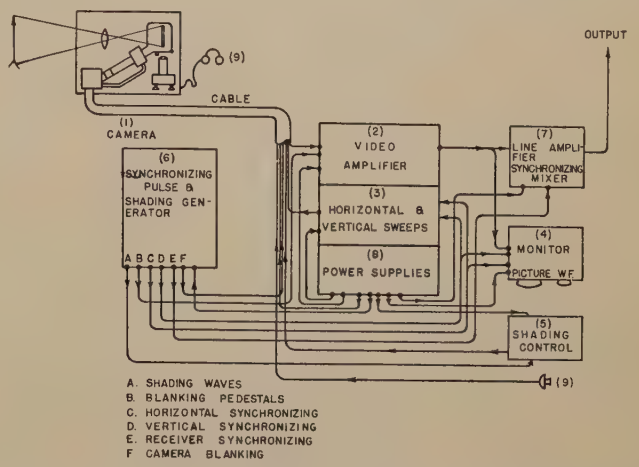

Fig. 11—Block diagram of single camera channel. Each channel in a multichannel installation requires duplication of this apparatus with exception of the pulse generator and the line amplifier which are common to all channels.

In the control room, the incoming picture signal is further amplified by the video amplifier, correction is made for the frequency and phase characteristics of the input circuit of the "head" amplifier, and blanking pedestals are added to the signal. The gain of this amplifier is adjusted so that the resulting output voltage is about 1 volt peak to peak, this voltage representing the excursion from black to white in the picture. The output of the amplifier is fed to a monitor and to a line amplifier which delivers its output to the television transmitter. The line amplifier serves also to add receiver synchronizing to the video wave, so that but one transmission line is needed to connect the studio with the picture transmitter.

The synchronizing pulse generator times the occurrence of the sweeps and blanking so that all the operations performed by the various pieces of equipment fit together precisely. The entire pulse generator is locked to the power line in such a manner that small erratic changes in line voltage or phase do not affect the operation of the apparatus which is synchronized from its outputs.

The stability of all components of the apparatus is dependent upon the power supply voltages available. All direct supply voltages are regulated by means of electronic regulator circuits which prevent normal line voltage variations from affecting the amplifiers and sweep circuits. No batteries or rotating machines are used.

The basic system employed in single-channel apparatus is repeated for each added channel in a multiple-channel installation. The several channels are co-ordinated by means of the program and monitor consoles as shown in Fig. 7. This diagram is simplified considerably in order to illustrate the functions of the consoles more clearly. The outputs of the channels are monitored separately and the video signals brought to the program console where they may be switched or faded into the mixing amplifier. The output of this amplifier feeds both the line monitor and the line amplifier with video signals which may be comprised of pictures from any one or two of the channels of the system. Receiver synchronizing is added to the video signals passing through the line amplifier to the transmitter, as is done in the case of the single-channel arrangement of Fig. 11.

Careful planning of power levels, impedances, signal polarities, and other like considerations allows a control system such as the one described to be built so that no trouble is experienced with cross talk between channels or with transients caused by switching or fading operations. Several special circuits which have been devised for the video amplifiers merit detailed consideration, since the wide-band amplifier circuits used in this system have contributed very greatly to its success.

The problem of the input circuit of a video amplifier associated with a camera tube such as the "iconoscope" has received much attention,[3] since the signal-to-noise ratio encountered at this point generally determines the signal-to-noise ratio of the entire amplifier system. However low the noise level at the input of the amplifier can be made, it is reasonable to assume that the signal input from the camera tube will be adjusted to a value only slightly above that which produces objectionable noise in the picture. This follows directly, since considerable improvement in the picture signal can be obtained by operating an iconoscope with as low a beam current (hence output) as possible, and by stopping down the lens to give improved depth of focus, with a corresponding drop in signal output. When better camera tubes and amplifiers are available, the illumination of the subject can be reduced to the point where the noise encountered is just below an objectionable value.

The definition of an objectionable signal-to-noise ratio in a picture signal is dependent on the type of noise present and the conditions under which the picture is viewed. The noise spectrum encountered in the video range can be "weighted" to account for the subjective effect upon observers, in much the same manner as is done in the audible range. For the purpose of illustration, the spectrum can be divided into four general ranges with respect to the scanning system used:

1. Very low frequencies from practically zero to 15 or 20 cycles per second, or a fraction of the picture-repetition rate. Noise frequencies in this range cause eye fatigue even if relatively small amounts are present.
2. Low frequencies from picture-repetition rate to a fraction of the line-repetition rate. Although no appreciable eye fatigue is caused by noise in this range, very annoying interference with the picture is produced.
3. Medium frequencies from line-repetition rate to ten or twenty times this rate. The effect of noise in this range will depend on the exact frequency of the interference, becoming more noticeable when harmonically related to the line-scanning frequency.
4. High frequencies from about twenty picture elements to one picture element in "pitch." The effect of noise in this range will be similar to that of the medium-frequency range, except that generally a given amount of high-frequency noise voltage causes less observable effect than the same amount of the medium-frequency noise voltage. Because this range is wider than the total of the first three, it will embrace the greatest amount of random-noise energy.

It has been found advantageous to treat groups 1 and 2 in the above list together as low frequencies which are most objectionable to the average observer. The division of the entire video-frequency spectrum into the resulting three major frequency ranges allows the design of the video amplifier to take good account of conditions which exist at the output of the camera tube.

The internal impedance of tubes such as the iconoscope or orthicon is so high that they may be considered as driving small video-frequency currents into the input impedance of the amplifiers over a wide impedance range. Because of unavoidable shunt capacitance associated with the camera tube, input circuit of the amplifier, and stray wiring capacitances, the load impedance into which the camera tube works will not be uniform over the entire video-frequency spectrum unless a low resistance is used as the load and suitable compensation employed to insure a reasonably uniform time delay. This load would be similar to the so-called "shunt-peaked" type of impedance commonly used as an interstage coupling network in video amplifiers. Although no subsequent frequency compensation would be required, the input voltage across such an impedance would be small, and the signal-to-noise ratio at the first stage of the amplifier would be poor.

Microphonic noise in the amplifier and alternating-current heater circuit disturbances lie in the low-frequency range which accounts for the most objectionable interference with the picture. If the load impedance for the camera tube is made relatively high at low frequencies, the over-all signal-to-noise ratio at

[3] Allen A. Barco, "An iconoscope pre-amplifier," *RCA Rev.*, vol. 4, pp. 89–107; July, 1939.

these low frequencies would be improved by subsequent compensation which corrects for the frequency characteristic of the input circuit at a higher voltage level. The existing shunt capacitance causes the impedance to fall gradually with increasing frequency, the load circuit consisting of parallel resistance and capacitance, as shown in Fig. 12. Exact compensation for an input circuit of this type is obtained by a current-driven series connection of inductance and resistance whose time constant is equal to that of the parallel resistance-capacitance network.[3]

The compensation for the network of Z_1 by that of Z_2 is unique.[4] It is not possible to provide two cascaded compensating networks so that the ratio of voltage-frequency compensation of each can be kept small in each and yet maintain the almost perfect compensation afforded by the simple network Z_2 of Fig. 12. Alteration of the input network, however, permits the resulting frequency characteristic to be compensated in two successive networks with much less danger of amplifier overload than might occur in the arrangement of Fig. 12. With the use of an input network such as Z_3 in Fig. 13, the same over-all variation in impedance between the lowest and the highest frequency encountered may be obtained as in the input network of Fig. 12, but exact compensation may be made in two steps. Fig. 14 shows the impedance of Z_1 for comparison with that of Z_3. The impedance of Z_3 is high at the lowest frequency where the greatest interference is encountered, medium at the middle range, and practically the same as Z_1 in the high range. It is important that the first break in the curve be made to occur above the range of microphonic tube noise, say above 2000 cycles, yet be essentially complete where the effects of C_1 on the second "step" begin to show. The wide frequency band (0 to 5 megacycles) represented in Fig. 14 allows compensation of the two ends of the band to be treated separately, and, therefore, to be accomplished in successive stages of the amplifier.[5]

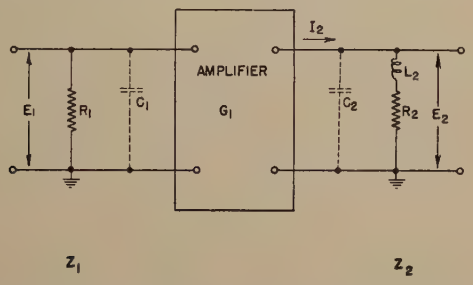

Fig. 12—Compensation for simple input circuit. When $L_2/R_2 = R_1C_1$, compensation is obtained for the effects of C_1 on the input voltage to the amplifier. (See appendix A.)

For example, the voltage which appears across Z_3 of Fig. 13 will be proportional to Z_3 for uniform input currents I_1 lying in the video-frequency band. If the output current of the amplifier is proportional to this voltage, the network Z_4 will compensate exactly for the low-frequency "hump" of Z_3 while not affecting the high-frequency end of the characteristic. This is true when R_6, L_6, and C_6 are proportioned to provide flat high-frequency response in the usual "shunt-peaking" method of wide-band amplifier compensation. The voltage E_4 will then bear the relation shown by curve A in Fig. 14 to the current I_1 and the relation shown by curve B to the current I_4. The voltage range of compensation remaining is considerably less than that which is required of Z_2 in an arrangement such as shown in Fig. 12, although curve A is mathematically similar to Z_1 of Fig. 12 and can be compensated almost exactly by a network of the same type as Z_2. The current I_8, which is proportional to E_4, causes the voltage E_8 to appear across Z_8. This voltage is proportional to I_1 over the video-frequency band of 5 megacycles when $L_8/R_8 = R_3C_1$, if the resonant frequency of Z_8 is approximately[4] 15 megacycles. The voltage E_8 then represents light and dark areas of the camera tube (taken in the order of scanning) in correct phase and amplitude, provided, however, that no component of spurious signal resulting from scanning is represented by I_1 and that G_1 and G_2 are independent of frequency within the video-frequency band.

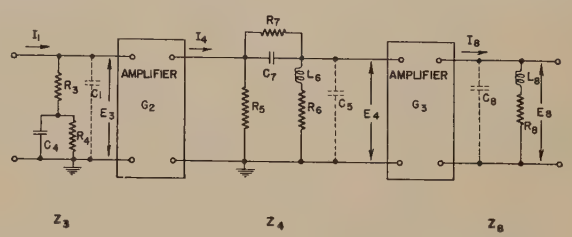

Fig. 13—Simplified diagram of cascade compensation of input circuit. Alteration of the input circuit allows compensation to be made in two steps in order to prevent amplifier overload by uncompensated signals. (See appendix B.)

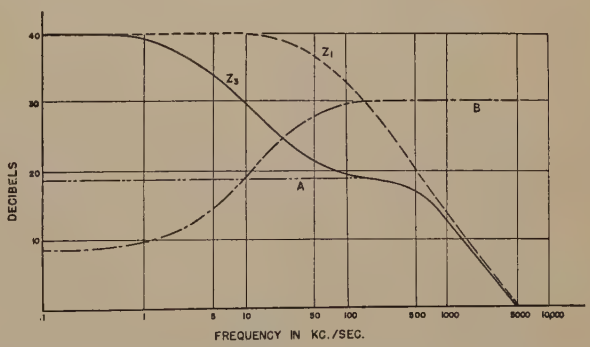

Fig. 14—Current, voltage, and impedance relations in cascade compensation system. Although Z_3 covers the same range of impedance as does Z_1, compensation of the low-frequency end of the curve may be made independent of the high-frequency end.

A circuit which utilizes a cathode-coupled input stage for reduction of C_1 is employed in the amplifier G_2 of Fig. 13. This permits a choice of higher values of R_3 and R_4 (in Z_3) which results in a greater input voltage E_3 to the amplifier for a given camera-tube output current. The excellent treatment given this method by others makes it unnecessary to discuss the details in this paper.[3]

[4] See Appendix A.
[5] See Appendix B.

Certain aspects of the compensation methods used make the particular basic forms of the networks shown in Fig. 13 very attractive from a practical point of view. Fig. 15 shows the network Z_4' used as an interstage coupling network in a slight modification of Z_4. The ability of this network to give perfect compensation of very low frequencies and input currents is destroyed in this modification, but this is advantageous since I_1 has no direct-current component in most cases. The choice of C_5 can be made to effect a low-frequency cutoff at any reasonable value desired. Its stray capacitance to ground can be neglected if ordinary care is taken to make that value reasonably small. The low values of L_8 and R_8 make a simple current-drive system give satisfactory gain and combined frequency-and-phase—response linearity. The "shunt-peaked" type of interstage load has many desirable properties when applied in multistage video amplifiers. Its response to transient excitation is good, adjustment for uniform gain over the desired band is simple and straightforward, and the gain which can be realized under usual conditions is adequate. Excellent treatment of the subject has been given in numerous other papers[6,7] and need not be discussed in detail in this paper.

Compensation of low-frequency response should be done in a manner that will not add shunt capacitance to the network, for the gain which can be realized is inversely proportional to the capacitance to ground.

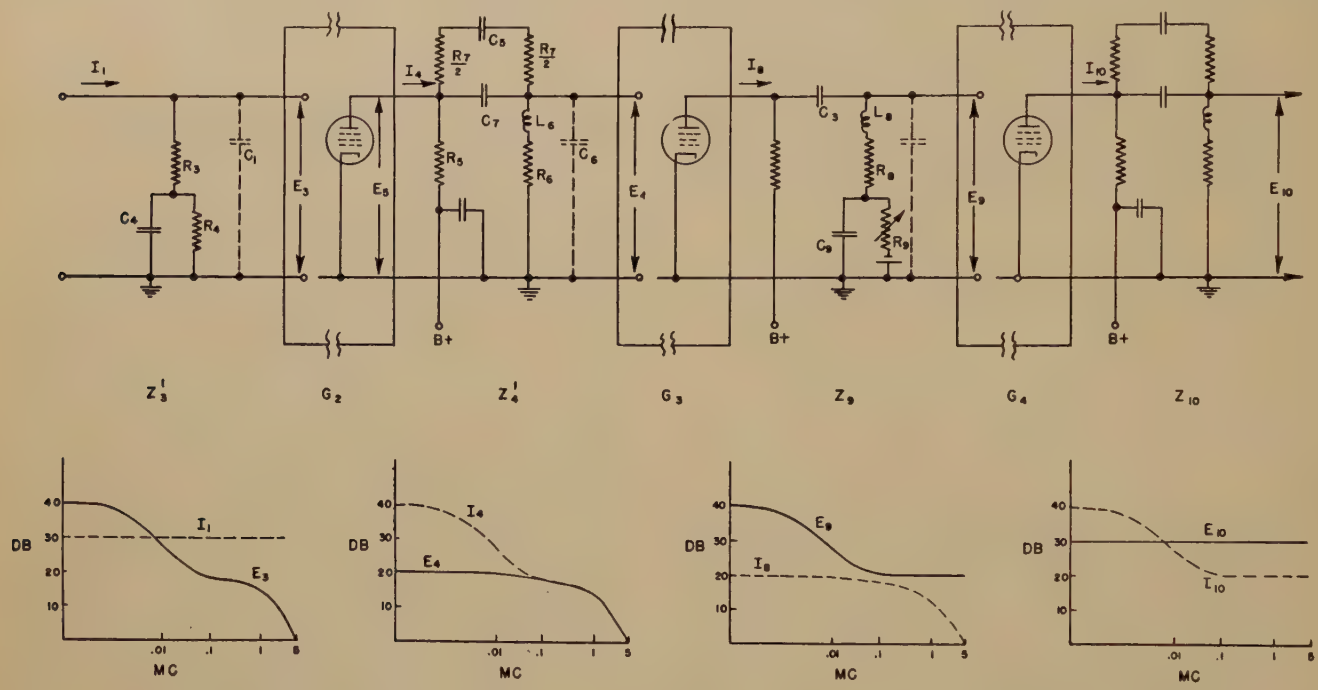

Fig. 15—Simplified circuit of cascade compensation system. The circuit operates as shown in the small curves below each impedance where a departure from "flat" response occurs.

practical and offer the opportunity of combining the principles of Z_3 and Z_8 to achieve low-frequency output voltages high enough to override microphonic noises in the amplifier stages to follow. Subsequent compensation by network Z_{10} (which is similar to Z_4') provides a voltage E_{10} which is proportional to I_1 over the entire video-frequency band and which is extremely free from microphonic and other tube noise. The small graphs of voltages and currents in Fig. 15 show the signal conditions at each stage where a departure from uniform response occurs. The dotted curve in each case represents the current which is fed into the network, while the solid curve represents the voltage appearing across the output of the network. R_9 is made variable so that bias sources having different resistances can be accommodated readily.

It has been found that the most practical method of compensating the high-frequency response of a video amplifier is to employ the simplest network which will Consequently, the circuit shown in Fig. 16 is used to effect very good low-frequency compensation, while actually improving (by decreasing the effective shunt capacitance at high frequencies) the performance of the stage in the high-frequency range. Since low-frequency phase shift is in a direction opposite to the high-frequency phase shift, the amount in each stage should be made very small to avoid a large cumulative effect when many stages are cascaded in order to provide high gain. Provision of very good low-frequency response in the video system allows transients to be reproduced without the objectionable "bounce" experienced with video amplifiers which do not reproduce very low frequencies faithfully.

The network comprising R_d and C_d (Fig. 16) acts

[6] A. C. Stocker, "An oscillograph for television development," Proc. I.R.E., vol. 25, pp. 1012–1033; August, 1937.

[7] S. W. Seely and C. N. Kimball, "Analysis and design of video amplifiers," *RCA Rev.*, vol. 3, pp. 290–308; January, 1939. (See notes on page 308.)

both as a decoupling circuit and as part of the low-frequency compensation circuit. The phase-shift and amplitude characteristic occasioned by this network is compensated by proper proportions[8] of R_1, R_g, C_g, and R_1 which comprise the remainder of the network when considered at low frequencies. The circuit is capable of passing uniformly all frequencies from 0 to 5 megacycles when C_2 is short-circuited and proper bias applied to the lower end of R_g to result in the desired bias at the grid of V_2. Proper high-frequency compensation by means of L_1 which takes account of C_s is carried out in the usual manner. The use of a physically small coupling capacitance C_g in this circuit permits C_s to be smaller than in conventional circuits, yet the low-frequency response is materially improved by the use[9] of R_1. Choice of C_2 allows the low-frequency cutoff to be adjusted without affecting the high-frequency characteristics of the coupling network. The phase shift at low frequencies is small when the reactance of C_2 is small compared with R_1, this portion of the circuit being similar to the corresponding part of Z_4' shown in Fig. 15.

The method used in the video system for maintaining black level is simple and effective. The video signal which comes from the camera amplifier has no blanking pedestals. Instead, the video wave during this time may contain extraneous voltages caused by camera blanking and a certain amount of feed through from the camera sweeps. It is necessary to replace these signals with flat-topped blanking pedestals so positioned with respect to the video signals that the tops of the pedestals represent black regardless of the content of the picture.

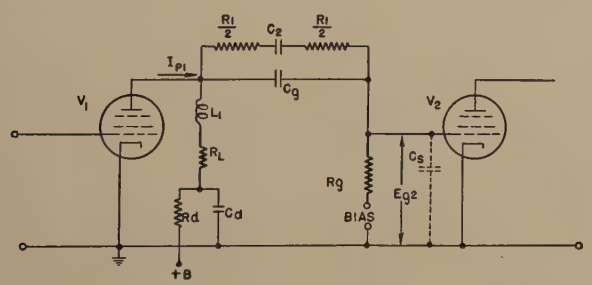

Fig. 16—Basic interstage coupling network. The response of this coupling circuit can be made essentially flat over the range from 10 cycles per second to 5 megacycles per second using capacitors no larger than 1 microfarad. (See appendix C.)

Fig. 17 shows a portion of the video amplifier in which the insertion of the direct-current component and blanking pedestals is carried out. The input signal to amplifier tube V_3 contains both the desired video signal and the undesired voltages represented by the wave form at this point. Amplified and inverted in polarity, this wave appears at the plate of V_4 and the grid of V_5. The positive excursions of the wave during the forward trace (during the desired signal) extend only to the line A-A, which represents ground potential. The positive direction represents the dark portions of the signal at this point because the tube V_4 is prevented from acting during the flyback time. Extraneous voltages at this part of the wave, therefore, will not necessarily lie below the line A-A. Application of positive pulses[10] on the cathode of V_4 during the flyback or blanking time prevent its action, so that the most positive peaks during the active period lie on the line A-A. The time constant of condenser C_c and re-

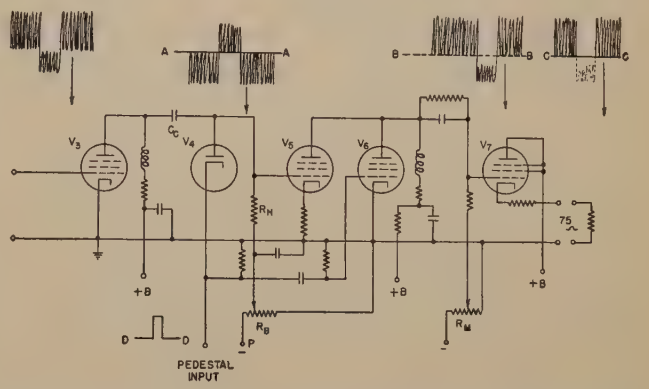

Fig. 17—Black-level control circuit. Application of positive pulses to the cathode of V_4 during flyback prevents its action during this period. V_7 is direct-current-coupled to V_5 by a circuit derived from that of Fig. 16.

sistor R_H is made long compared with 60 cycles, but short compared with that of the preceding part of the amplifier. If the slider on R_B be connected to ground, a direct voltage proportional to the positive peak of the video wave will appear across R_H and the grid of V_5. The input of V_5 appears on the grid of V_7 amplified and inverted and mixed with pedestal pulses supplied by V_6. The bias on V_7 is adjusted by the voltage divider R_M so that negative excursions of the wave fall below the cathode-current cutoff line B–B. The current in the cathode circuit of V_7 thus falls to zero (line C–C) during the pedestals, thereby "clipping" the portion of the wave which falls below the cutoff line and substituting a pedestal signal. Note that V_7 is direct-current coupled to V_5, so that the direct-current insertion action of V_4 is transferred to V_7 as well as the video signal.

If the most positive video signal applied to V_4 is always one representing black, then V_4 in setting these peaks to a definite reference line such as A–A will accomplish direct-current insertion automatically. When the brightness of a scene changes abruptly from light to dark (or vice versa) there will be no appreciable "bounce" because the time constant of the amplifier is greater than that of the direct-current insertion circuit. The circuit fails to operate properly when a scene contains either insufficient areas of black or none at all. Most scenes, however, provide correct automatic operation of the circuit. Supplementary manual control is made possible by adjustment of R_B to a point which

[8] See Appendix C.

[9] This circuit is similar to that shown by A. Preisman in his paper, "A wide-range video amplifier for a cathode-ray oscilloscope," *RCA Rev.*, vol. 3, pp. 473–485; April, 1939, except that R_1 is divided into two equal parts by insertion of C_2.

[10] These pulses have a base line D-D which is at ground potential.

gives the necessary direct voltage at V_5. Any setting of R_B below that set automatically by V_4 will be ineffective in reducing the direct-current component. It is, therefore, impossible to "clip off" some of the black portions of a signal in V_7 when R_M is set properly.

In systems where the direct-current component is supplied separately by a photoelectric cell which integrates the light contained in a picture,[11] the cell may be connected to point P of R_B. R_B may be adjusted so that the direct-current signal applied to V_5 is properly related to the alternating-current signal coming through the amplifier.

The output of the amplifier matches a 75-ohm cable which is terminated by a resistance load. The output signal is composed of video signals plus pedestals with black at zero volts. White is positive, with a normal maximum peak value of 1 volt. The direct-current component of the video signal is contained in the output of the amplifier in a most convenient form, for black is always zero current in the load. This is important when switching or fading from one channel to another, since there is no possibility of causing a transient which will interfere with the black reference level from which the synchronizing pulses rise. No adjustment of this reference level is required, since it is determined automatically by cathode-current cutoff of the clipper tube V_7 regardless of the direct-current component present in the signal.

The horizontal and vertical camera sweep generators embrace circuits which permit the generated wave forms to be adjusted to give linear scanning of the rectangular camera mosaic. Each wave form must be altered from a saw-tooth form to take account of the resistance of the deflection coils and the impedance of the driving circuits. Also, correction must be made in the wave forms supplied to the coils in scanning a mosaic which is inclined to the axis of the electron gun, as in the "iconoscope" type of camera tube. The horizontal wave form, in this case, must be modulated with a saw-tooth wave of vertical frequency, while the slope of the vertical scanning current wave must be adjusted so that the velocity of the scanning beam is uniform along the vertical direction of the mosaic. The horizontal and vertical circuits are contained in the same piece of equipment because 60-cycle vertical saw-tooth waves are used in modulating the horizontal waves.

Vertical deflection current is sent through the camera cable directly to the coil, since an inexact termination of the cable does not distort the transmission of low-frequency waves noticeably. In the case of the horizontal deflection, however, a coupling amplifier in the camera is used to drive the scanning current through the coil while allowing the cable carrying the horizontal driving voltage to be terminated in such a way as to permit no wave-form distortion to occur in transmission to the camera over cables of appreciable length. The sweep generator is provided with protective circuits which cut off the camera beam current when the amplitude of the scanning current in either of the coils falls below a predetermined value. These protection circuits are designed to fail "safe," so that maximum protection is assured.

[11] E. W. Engstrom, G. L. Beers, and A. V. Bedford, "Application of motion picture film to television," *RCA Rev.*, vol. 4, pp. 48–61; July, 1939.

Audio Equipment

The best commercial broadcast studio practice is followed in the design of the audio equipment, and full-range frequency response is provided. The system is flat within 2 decibels from 25 to 15,000 cycles per second. Four preamplifiers, a studio amplifier, and a monitor amplifier, with their power supplies, are located in an audio rack in the control room. A patch board on this rack allows flexibility in the use of the channels provided. All the attenuators, switches, and other controls are remotely located on the program console. The equipment is capable of a producing high fidelity, noise-free audio output to accompany the high-definition video signals.

Conclusion

Operating results obtained with the system described have indicated the soundness of the principal features employed. The effective use of the communication systems which are integral parts of the program console prove the value of high-quality circuits and sufficient multiplicity to prevent confusion among members of the staff. Dual-purpose audio and video channels and multiple monitoring facilities have simplified and improved rehearsal and program technique by allowing a number of control operations to be carried on simultaneously without an increase of personnel. Operators learn their jobs quickly and do not complain of fatigue even after all-day sessions of rehearsal and programs.

The ease of expansion permitted by the design of the control equipment is a feature which will allow growth of studio facilities to take care of broadcasting requirements. Addition of channel equipment can be accomplished without shutdown or operating inconvenience. The appearance of the control equipment does not suffer from planned growth of this type.

Close grouping of monitoring and quality controls permits picture quality to be maintained at optimum values without loss of production efficiency. Special effects such as lap-dissolves and fading, which add much to program interest, are accomplished easily with simple control circuits. The supplementary signal lights assist control operators in co-ordination of their activities toward a finished appearance of the program.

The special circuits employed throughout the system result in dependable performance under all operating conditions. The compensation circuits employed in the video amplifier system allow simplified align-

ment procedure and provide improved performance over conventional arrangements.

Acknowledgments

The development of a complete control system has required the effort of many persons. In particular, the authors wish to mention the work of Messrs. F. M. Deerhake, J. F. Wiggin, and O. H. Petersen, whose help in planning and building the equipment described has contributed greatly to its success. Valuable suggestions by members of the program and operating staff of W2XB are hereby acknowledged.

Appendix A

Analysis of Compensating Circuits of Fig. 12

The voltage appearing across the load circuit (impedance Z_1) is

$$E_1 = I_1 Z_1 = I_1 \left(\frac{-j\frac{R_1}{\omega C_1}}{R_1 - j\frac{1}{\omega C_1}} \right), \tag{1}$$

where I_1 = the camera-tube output current,
R_1 = the shunt resistance,
C_1 = the shunt capacitance, and
$\omega = 2\pi$ times the frequency under consideration.

If the amplifier coupling Z_1 with Z_2, which is the compensation network for Z_1, be considered to have a uniform frequency characteristic, its mutual conductance may be represented by a term G_1 which is independent of ω.

$$I_2 = G_1 E_1 = G_1 I_1 \left(\frac{-j\frac{R_1}{\omega C_1}}{R_1 - j\frac{1}{\omega C_1}} \right), \tag{2}$$

from which

$$E_2 = I_2 Z_2 = G_1 I_1 \left(\frac{-j\frac{R_1}{\omega C_1}}{R_1 - j\frac{1}{\omega C_1}} \right) (R_2 + j\omega L_2) \tag{3}$$

where R_2 and L_2 are the series elements comprising Z_2, and E_2 is the voltage across Z_2. Equation (3) may be written

$$E_2 = G_1 I_1 \left(\frac{\frac{L_2 R_1}{C_1} - j\frac{R_1 R_2}{\omega C_1}}{R_1 - j\frac{1}{\omega C_1}} \right). \tag{4}$$

If the phase angle indicated in the numerator of the factor of (4) be made equal to that of the denominator, then E_2 will be related to I by constant multipliers.

$$\left(\frac{R_1 R_2}{\omega C_1}\right) \Big/ \frac{L_2 R_1}{C_1} = \left(\frac{1}{\omega C_1}\right) / R_1. \tag{5}$$

Canceling,

$$L_2/R_2 = R_1 C_1, \tag{6}$$

or the time constant of Z_2 equals that of Z_1 for this condition. If the value of L_2 in terms of R_2, R_1, and C_1 be substituted in (4), then

$$\begin{aligned} E_2 &= G_1 I_1 \frac{\left(\frac{R_1^2 R_2 C_1}{C_1} - j\frac{R_1 R_2}{\omega C_1} \right)}{R_1 - j\frac{1}{\omega C_1}} \\ &= G_1 I_1 R_1 R_2 \left(\frac{R_1 - j\frac{1}{\omega C_1}}{R_1 - j\frac{1}{\omega C_1}} \right) = G_1 I_1 R_1 R_2 \end{aligned} \tag{7}$$

and is independent of ω. Furthermore, there is no phase angle or time delay in this compensation if G_1 is truly independent of ω.

In this analysis, the presence of unavoidable shunt capacitance C_2 associated with Z_2 has been neglected. If the resonant frequency of the network including C_2 is made approximately three times the upper limit of ω in (1), the effect of C_2 can be neglected with good approximation of the ideal case just treated. The necessity of providing such a resonant frequency imposes a serious limitation on the method, since R_2 and L_2 must be limited to exceptionally low values if any real benefit is to be gained from the increase of input impedance at low frequencies. Equation (7) shows that E_2 is directly proportional to R_2 and G_1. E_2 must be larger than E_1 at all frequencies in order to provide the following amplifier stage with a signal considerably above microphonic and random noise referred to Z_2. Since R_2 has a small maximum practical value limited by the presence of C_2, G_1 must be large enough to bring E_2 sufficiently above the effective noise level at this point. It is difficult to obtain the two conditions, namely, E_1 well above the noise level, and G_1 high enough to produce across Z_2 an E_2 even higher than E_1 without low-frequency overload of the tubes used to obtain G_1. Selective overload has somewhat the same effect as imperfect compensation, since G_1 under these conditions is a function of frequency.

Appendix B

Analysis of First Two Compensating Circuits (Z_3' and Z_4') of Fig. 15

The input current I_1 to the network Z_3' is assumed to be essentially independent of the voltage E_3 across this network. It is essential to correct for the frequency discrimination introduced intentionally at the input circuit before the signal is used, but this correction should be made with particular regard to the phase characteristic of the over-all signal as well as amplifier

overload levels. The impedance characteristic of Z_3' is shown in Fig. 14 over a band extending to 5 megacycles. The effect of C_1 on the impedance is negligible up to 100,000 cycles, while the effect of R_4 and C_4 is negligible beyond 100,000 cycles in the particular case treated. Therefore, the over-all compensation can be divided between two networks which operate over these two ranges independently. Treatment of the network which compensates the high-frequency end of the band has been given in Appendix A, in which the compensation applies to the circuit elements R_3 and C_1 in shunt. The compensation network Z_4' of Fig. 15 compensates the low-frequency end of the band for the effects of the circuit represented by R_3 in series with R_4 and C_4 in shunt, neglecting the effect of C_1 in this frequency range.

Referring to Fig. 15, assume I_1 to be the current input to the network Z_3'. The voltage across Z_3' caused by this current is approximately

$$E_3 = I_1 Z_3' = I_1 \left(R_3 - \frac{j\frac{R_4}{\omega C_4}}{R_4 - j\frac{1}{\omega C_4}} \right), \tag{8}$$

where $\omega = 2\pi$ times frequency (up to 100,000 cycles per second). If G_2 be defined as a composite[12] mutual conductance which is independent of frequency over the range considered, then

$$I_4 = G_2 E_3 \tag{9}$$

[12] G_2 may be obtained by a flat compensated amplifier consisting of several stages.

if the plate impedance of the tube be included in R_5. Neglecting C_6 for the moment and letting $L_6 = 0$,

$$Z_4' = \frac{\left(R_6 - \dfrac{jR_7\dfrac{1}{\omega C_7}}{R_7 - j\dfrac{1}{\omega C_7}} \right) R_5}{R_6 + R_5 - \left(\dfrac{jR_7\dfrac{1}{\omega C_7}}{R_7 - j\dfrac{1}{\omega C_7}} \right)} \quad \text{when } C_5 = \infty. \tag{10}$$

Then,

$$E_4 = \left[\frac{R_6}{R_6 - \left(\dfrac{j\dfrac{R_7}{\omega C_7}}{R_7 - j\dfrac{1}{\omega C_7}} \right)} \right] I_4 Z_4'. \tag{11}$$

Substituting I_4 from (9) and Z_4' from (10) in (11),

$$E_4 = \left[\frac{R_6}{R_6 - \left(\dfrac{j\dfrac{R_7}{\omega C_7}}{R_7 - j\dfrac{1}{\omega C_7}} \right)} \right] G_2 E_3 \left[\frac{\left(R_6 - \dfrac{j\dfrac{R_7}{\omega C_7}}{R_7 - j\dfrac{1}{\omega C_7}} \right) R_5}{R_6 + R_5 - \left(\dfrac{j\dfrac{R_7}{\omega C_7}}{R_7 - j\dfrac{1}{\omega C_7}} \right)} \right]. \tag{12}$$

Simplifying and substituting E_3 from (8),

$$E_4 = \frac{R_6 R_5 G_2 E_3}{R_6 + R_5 - \left(\dfrac{j\dfrac{R_7}{\omega C_7}}{R_7 - j\dfrac{1}{\omega C_7}} \right)} = \frac{R_6 R_5 G_2 I_1 \left(R_3 - \dfrac{j\dfrac{R_4}{\omega C_4}}{R_4 - j\dfrac{1}{\omega C_4}} \right)}{R_6 + R_5 - \left(\dfrac{j\dfrac{R_7}{\omega C_7}}{R_7 - j\dfrac{1}{\omega C_7}} \right)}. \tag{13}$$

If now

$$R_6 + R_5 = AR_3 \tag{14a}$$

$$R_7 = AR_4 \tag{14b}$$

and

$$C_4 = AC_7 \tag{14c}$$

where A is a real number, and these values be substituted in (13), the equation

$$E_4 = \frac{G_2R_5R_6I_1\left(\dfrac{R_6+R_5}{A} - j\dfrac{\dfrac{R_7}{A}\dfrac{1}{\omega AC_7}}{\dfrac{R_7}{A} - j\dfrac{1}{\omega AC_7}}\right)}{R_5+R_6-j\left(\dfrac{\dfrac{R_7}{\omega C_7}}{R_7 - j\dfrac{1}{\omega C_7}}\right)} \quad (15)$$

is obtained. Simplifying,

$$E_4 = \frac{G_2R_5R_6I_1}{A}. \quad (16)$$

Substituting $A = R_7/R_4$,

$$E_4 = G_2I_1\frac{R_5R_6R_4}{R_7}. \quad (17)$$

Thus E_4 is proportional to I_1 under the conditions assumed, i.e., in the frequency range up to 100,000 cycles. The combination of R_6, L_6, and C_6, which represents the total stray capacitance encountered in an interstage coupling network, is proportioned for uniform impedance over the entire frequency spectrum up to 5 megacycles. The high-frequency compensation thus is delayed until the signal is amplified further.

Note that when C_5 is assumed infinite, (17) holds true at zero cycles if the amplifier G_2 will pass direct-current input signals. Practical values of low-frequency cutoff in the amplifier make the insertion of C_5 in R_7 of no consequence as far as signal amplification is concerned, but blocks the plate voltage from the grid circuit of the following amplifier. Its stray capacitance to ground has but slight effect on the high-frequency characteristic of the network because of the decoupling effect of the two halves of R_7. Nominal values of the stray capacitance will, likewise, have small effect on the mid-frequency characteristics. The low-frequency phase shift and amplitude characteristic of the network will be good at frequencies where the impedance value of C_5 is small compared to R_7. An example of the values of components used in Z_3' and Z_4' will show that a reasonable value of C_5 is realized easily in practice.

Z_3'	Z_4'
$R_3 = 50{,}000$ ohms	$R_5+R_6 = 21{,}000$ ohms ($A = 0.42$)
$R_4 = 500{,}000$ ohms	$R_6 = 1{,}000$ ohms
$C_4 = 100$ micro-microfarads	$R_7 = 210{,}000$ ohms
	$C_7 = 238$ micromicrofarads
$C_1 = 6$ micromicro-farads	$R_5 = 20{,}000$ ohms (includes R_p)
	$C_6 = 31.8$ micromicrofarads (stray, etc.)
	$L_6 = 31.8$ microhenrys
	$C_5 = 1.0$ microfarad

The phase shift occasioned by C_5 is only 4 degrees at 10 cycles per second; the amplitude response is correspondingly good.

The current forced through Z_9 causes a low-frequency "hump" of E_9 similar to that of E_3. This is compensated by the network Z_{10} which is related to Z_9 (below 100,000 cycles) in the same manner as are Z_4' and Z_3', just treated. The low-frequency phase shift caused by C_3 may be made negligible by a suitable choice of the plate coupling resistor and of C_3.

Appendix C

Low-Frequency Compensation in Video-Frequency Coupling Network

In the circuit shown in Fig. 16 considered at low frequencies the plate current I_p, of V_1, will divide between the two branches of the network in a constant ratio independent of frequency when the impedances of the two branches are proportional. Thus, if

$$R_g/R_L = K \quad (18)$$

$$R_1/R_d = K \quad (19)$$

$$C_d/C_g = K \quad (20)$$

where K is a real number, the impedance of the right-hand branch is K times that of the left-hand branch, and

$$E_{g_2} = I_{p_1}R_g\left(\frac{1}{1+K}\right). \quad (21)$$

Equation (21) includes the case where C_2 is short-circuited. Under this condition the network will exhibit no low-frequency amplitude discrimination or phase shift. When it is desired to prevent direct-current coupling, C_2 can be chosen to give the desired low-frequency performance. Typical examples of practical values are given below:

$R_L = 1{,}000$ ohms
$R_g = 250{,}000$ ohms ($K = 250$)
$R_d = 10{,}000$ ohms
$R_1 = 2{,}500{,}000$ ohms
$C_d = 1$ microfarad
$C_g = 0.004$ microfarad
$C_2 = 1$ microfarad

The phase shift at 10 cycles when $C_2 = 1$ microfarad will be less than 0.37 degree. Good results are obtained when $C_2 = 0.1$ microfarad. Unavoidable capacitance between C_2 and ground will have negligible effect on the upper frequency range because of the high-frequency isolation provided by the two halves of R_1. Note that no capacitor over 1.0 microfarad is used, and that the value of C_g is conveniently small.

Measurement of Iron Cores at Radio Frequencies*

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Summary—*Iron cores are used in radio-frequency coils primarily to obtain increased inductance. The amount of inductance increase due to the iron core depends upon the physical dimensions of the coil and the core, and on the effective permeability of the core.*

In addition to the inductance increase, the iron core increases the effective radio-frequency resistance of the coil due to hysteresis and eddy-current losses in the iron.

This paper describes a method of measuring the effective permeability and loss factor of iron at radio frequencies, and develops expressions by means of which the characteristics of a given coil can be predicted when the iron constants are known. The measurement method described is employed to measure several cores. Sample calculations and curves are given to illustrate the use of the formulas developed herein.

Theoretical Considerations

(a) *Effective Permeability*

THE classic methods of measuring permeability usually involve a toroidal sample and coil in order to eliminate end effects. Not only are such samples highly special and the torus difficult to wind, but the results require conversion to practical coil forms to be useful. The most common form of coil in radio applications is the solenoid, so that both the measurement and performance expressions have been based on that type of coil. Other forms of coils, such as universal windings, may be used with proper consideration of the factors by which these differ from solenoids.

The self-inductance of any coil depends upon the flux linkages per unit current.

$$L = \frac{\phi N}{I} \tag{1}$$

where L = inductance
ϕ = flux
N = number of turns
I = current through the coil.

Now

$$\phi = BA \tag{2}$$

where B = flux density
A = area of cross section,

and

$$B = \mu H \tag{3}$$

where μ = permeability
H = induction.

Neglecting end effects,

$$H = \frac{4\pi NI}{l} \tag{4}$$

where l is coil length.

Then with a coil of circular cross section having a radius b,

$$L = \frac{\mu 4\pi NI\pi b^2 N}{lI} = \frac{4\pi^2 b^2 N^2 \mu}{l} \tag{5}$$

which is the form for the well-known expression for inductance of a solenoid with the exception of Nagaoka's constant K, which is a function of ratio of diameter to length. When the length is large compared with the diameter, K approaches unity. Expression (5) has been developed on the basis of absolute units, so that the result is in abhenrys. To express inductance in microhenrys, (5) must be multiplied by 10^{-3}, the dimensions being given in centimeters.

When the coil has an iron core, part of the cross-sectional area of the coil is occupied by iron and part by air. The inductance in that case is proportional to the total flux, which is different in the iron- and in the air-core portions. The induction H is the same in both if we assume that the length of coil and iron core are the same. If the length differs the analysis may be made by sections of length.

The flux in the iron due to H is equal to μ of the iron times the area of the iron times H, and the flux in the air-core portion is equal to μ of air (unity) times the area of the air-core portion times H. In the usual case, both the iron core and the coil have a circular cross section.

If we let b_i be the radius of the iron and b_0 be the radius of the coil, the inductance of the coil with an iron core L_i is given by

$$L_i = \frac{4\pi^2 N^2}{l}(b_0^2 - b_i^2 + \mu b_i^2) \tag{6}$$

but $4\pi^2 N^2 b_0^2/l$ is the inductance of the coil without iron or L_0, so that

$$L_i = L_0\left(1 + \frac{b_i^2}{b_0^2}(\mu - 1)\right). \tag{7}$$

This expression may be used to determine μ when L_i and L_0 are known or to calculate the effect on an inductance L_0 of a given diameter iron core if the effective permeability μ is known. The permeability is not that of the iron itself but of the iron as used in the core in laminae or particles, hence, it is called the effective permeability. The only assumption involved is that the core be homogeneous, that is, any one section of the core be like any other section.

It has been pointed out above that the end-correction factor K (Nagaoka's constant) has been neglected. This factor depends upon coil geometry, hence (6) will not be correct unless this factor is included. However, if K does not change when iron is added, (7) is strictly correct since K is implicit in L_0.

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The results of calculation of inductance by means of (7) are shown in Fig. 1 for two samples of iron of different effective permeability values. The cores were $\frac{3}{8}$ of an inch in diameter and the coil 1 inch long. The calculated inductance with core is shown by the curve and the points represent measured values. These curves show that there is good agreement between calculated and measured values and that this agreement holds even for coils whose diameter is less than the length. The observation that the end-effect constant K is not appreciably affected by the presence of the core is thus seen to be justified. These curves are for the case of a core shorter than the coil. The value of μ so determined is lower than is obtained with a longer core. To determine the maximum effective permeability of a material, the core length should exceed the coil length.

The effective permeability of the iron depends to some extent upon frequency, so that it is necessary to know the value for the frequency of interest to obtain accurate results from (7). The variation in effective permeability is small up to about 8 or 10 megacycles, as may be seen from Fig. 4, so for the lower frequencies μ may be considered a constant.

There is one other precaution to be observed in applying (6) or (7) when the core diameter is greater than about 0.8 of the coil diameter, that is, the effect of capacitance between the core and the coil on the apparent inductance. When the wall thickness of the coil is small, appreciable capacitance exists between the coil and the core which increases the apparent inductance. The effect of this capacitance depends upon the potential between the coil and the core and hence is influenced by whether or not the core is grounded.

(b) Loss Factor

The increase in resistance of a coil due to the presence of an iron core is also subject to rational treatment. This resistance increase is due to hysteresis and eddy-current losses in the core.

The power required to supply the coil losses is given by

$$W = I^2(R_0 + R_i). \tag{8}$$

Part of the coil losses are due to the radio-frequency resistance of the coil without the core, and part are due to the hysteresis and eddy-current losses in the iron. If a term involving I is not to be present in an expression for iron losses, it is necessary that the watts required to supply iron losses be proportional to the square of the flux density B. While this is not true for conditions where B is large, as in power applications, tests indicate that W_i does vary as B_i^2 for the range of flux density commonly used in radio-frequency applications.

Now from (3) we know that $B = \mu H$ and that H depends upon current and coil geometry. In the case of a determination of μ, we have seen that the end effects in the coil are small and where necessarily taken into account, can be given as a correction factor. In the case of resistance-effect calculations, the end effects are of more consequence since the loss is proportional to B_i^2. In any solenoid the flux at the ends is exactly

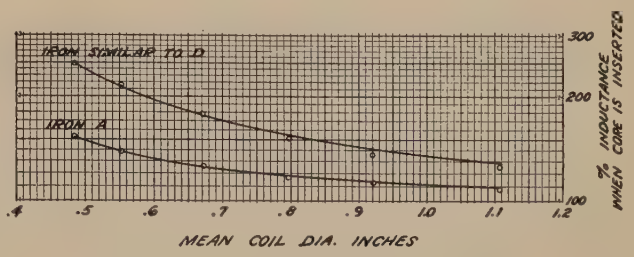


Fig. 1—Calculated and observed values of coil inductance with an iron core.
Coil length = 1 inch — Core diameter = $\frac{3}{8}$ inch
Core length = $\frac{3}{4}$ inch — Frequency = 9 megacycles
Solid lines are calculated
Circles are observed points

half that at the center, but the per cent of coil length over which the flux density will be the same as that at the center depends upon coil geometry. Accordingly, a more exact expression is necessary for H.

This form is

$$H = \frac{4\pi NI}{\sqrt{4b_0^2 + l_0^2}} \tag{9}$$

where b_0 = mean coil radius and
l_0 = coil length.

Now if the hysteresis and eddy-current losses vary as the square of the flux density, the power loss in the iron, W_i, is proportional to B_i^2.

Now

$$B_i = \frac{4\pi NI\mu}{\sqrt{4b_0^2 + l_0^2}} \tag{10}$$

and

$$W_i = I^2R_i \tag{11}$$

where R_i is equivalent resistance added to the coil by the presence of iron. The total core loss is also proportional to the core volume, so

$$W_i = B_i^2V_i\rho \tag{12}$$

where V_i = volume of the iron
ρ = specific loss factor for the iron.

Then

$$R_i = \left(\frac{4\pi N}{\sqrt{4b_0^2 + l_0^2}}\right)^2 \mu^2\pi b_i^2 l_i \rho \tag{13}$$

$$= \frac{16\pi^3 N^2 l_i b_i^2 \mu^2 \rho}{4b_0^2 + l_0^2}. \tag{14}$$

But we can write for the inductance of the coil without iron

$$L_0 = \frac{4\pi^2 b_0^2 N^2}{\sqrt{4b_0^2 + l_0^2}}. \tag{15}$$

This differs from (5) in the denominator, which means that Nagaoka's constant cannot be applied directly to (15) when the additional accuracy supplied by that factor is desired, but must be multiplied by the ratio of the denominators of (5) and (15).

Then

$$R_i = L_0 \left(\frac{4\pi\mu^2 b_i^2 l_i \rho}{b_0^2 \sqrt{4b_0^2 + l_0^2}} \right). \qquad (16)$$

From either (14) or (16) the factor ρ for the iron may be calculated. This factor then permits calculation of the resistance added to any solenoid from the mechanical dimensions of the coil and core, the number of turns, and the permeability of the core.

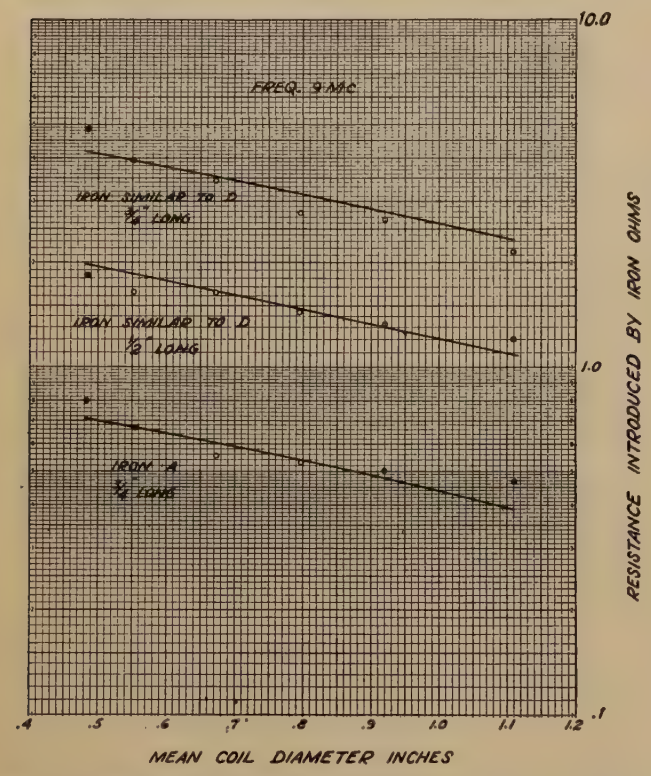


Fig. 2—Calculated and observed values of resistance introduced into coil by an iron core.
Coil length = 1 inch Core diameter = $\frac{3}{8}$ inch
Sold lines are calculated
Circles are observed points

The calculated values agree reasonably well with measured values as may be seen from Fig. 2. Here the lines represent calculated values of effective resistance due to the iron and the points represent measured values. Still closer agreement between measured and predicted values may be obtained when desired, by proper inclusion of Nagaoka's constant in the expressions. The additional complication is seldom warranted however.

The value of ρ derived from the expressions above varies greatly with frequency. If all the loss were due to eddy currents it would vary as the square of the frequency. In radio-frequency applications it does vary approximately as the square of the frequency, particularly for frequencies above 8 or 10 megacycles, as may be seen from Fig. 5. Consequently it is usually more convenient to express the loss factor as ρ per megacycle-squared rather than directly.

The expressions developed do not lend themselves to a simple expression for Q. If Q is desired, it is simpler to calculate L and R separately.

The expressions developed have their principal usefulness in separating the effects of the coil constants from the core constants. They permit comparing the effects of different types of iron cores directly. In this connection it must be remembered that the expression for R_i has the factor $\mu^2\rho$ so that of two iron samples of equal ρ, the one with highest μ frequently will not produce the highest Q in a given coil. The effect on Q depends not only on the μ and ρ of the core but also on the radio-frequency resistance of the coil without iron. Accordingly, all of the pertinent factors must be considered in comparing different iron samples, but when so considered the results become highly significant and useful.

Method of Measurement

Probably the most convenient and most generally available method for the measurement of coils with or without cores is the "Q meter." This instrument is versatile in measurement applications and gives results of satisfactory engineering accuracy over a wide range. However, under certain conditions, particularly at high frequencies, errors inherent in any device of this type must be considered. In this investigation it was found necessary to correct the data for these errors at frequencies of 9 megacycles and above.

Three sources of error must be considered for measurements made under certain conditions, particularly above 9 megacycles: (1) vacuum-tube Q-voltmeter loading, (2) internal circuit impedances within the Q meter, and (3) distributed capacitance of the coil being measured.

The effect of vacuum-tube Q-meter loading is to reduce the apparent Q of the coil under measurement. This source of error is important only at high frequencies where the input impedance of the vacuum-tube voltmeter becomes finite and comparable to the tuned-circuit impedance. In the present case this error was found to be negligible below 25 megacycles. In determining the amount of resistance introduced into a coil by a core, it is necessary to consider the effect of vacuum-tube-voltmeter damping because this damping changes when the inductance of the coil is altered by the core, and the apparent increment of coil resistance will contain a component due to the change of tube damping which must be removed to obtain that due to the core alone.

Unavoidable internal circuit impedance within the Q meter such as in the leads, coupling resistor, and tuning capacitor, lead to errors in Q and indicated inductance. These errors become important when measuring coils having low inductance and low resistance. The Q

meter used for measurement work in this study had an internal inductance of 0.078 microhenry, which made corrections necessary at 9 megacycles and above. The ratio of circuit inductance to coil inductance varied from 5 per cent at 9 megacycles to 52 per cent at 50 megacycles.

Internal circuit resistance must be considered in arriving at an absolute value of coil Q. In this study we are concerned only with changes of Q (and resistance) caused by the insertion of a core, therefore internal circuit resistance need not be considered if it remains constant. Spot checks indicated that the total internal circuit resistance was reasonably constant within the range of capacitor settings used, although the resistance of the tuning capacitor may be expected to vary to some extent with setting. Since these spot measurements indicated only small changes of total circuit resistance, and since the measurements were taken over a comparatively small range of capacitance variation, the circuit resistance was considered constant and was not corrected for.

The distributed capacitance of the coil being measured changes the apparent resistance, inductance, and Q of the coil. This source of error becomes important where the distributed capacitance of the coil is comparable to the tuning capacitance. For the measurements made in this study the distributed-capacitance error was so small as to be negligible, unless otherwise noted.

Correction factors for the errors discussed above are listed for convenient reference. The derivations of these expressions are given in Appendixes A, B, and C, respectively.

(a) Correction for Vacuum-Tube-Voltmeter Loading

$$Q = Q_a \left(\frac{1}{1 - \frac{Q_a}{\omega C R}} \right) \tag{17}$$

where,

Q = true Q of coil
Q_a = apparent Q of coil
C = capacitance to resonate coil at frequency, f
R = shunt input resistance of vacuum-tube voltmeter
$\omega = 2\pi f$.

(b) Correction for Internal Impedances

$$Q = Q_a \left(\frac{1}{1 - \frac{r_m}{r_a}} \right) \tag{18}$$

$$L = L_a - L_m. \tag{19}$$

In this study the change of inductance caused by the introduction of the core is of interest, so that a correction factor for converting the apparent change of inductance to the true change of inductance is given below.

$$\eta = \frac{\eta_a - \tau}{1 - \tau} \tag{20}$$

where,

Q = true Q of coil
Q_a = apparent Q of coil
L = true inductance of coil
L_a = apparent inductance of coil
L_m = internal inductance in Q meter
η = true change of inductance
η_a = apparent change of inductance
r_a = apparent resistance of coil
r_m = internal resistance in Q meter
τ = ratio of internal inductance L_m to indicated coil inductance without core (L_a with core removed).

(c) Correction for Distributed Capacitance of Coil

$$L = -L_a \left(\frac{C_d}{C} - 1 \right) \tag{21}$$

$$r = r_a \left(\frac{C_d}{C} - 1 \right)^2 \tag{22}$$

$$Q = Q_a \left(\frac{1}{1 - \frac{C_d}{C}} \right) \tag{23}$$

where,

L = true inductance of coil
L_a = apparent inductance of coil
r = true resistance of coil
r_a = apparent resistance of coil
Q = true Q of coil
Q_a = apparent Q of coil
C_d = distributed capacitance of coil
C = tuning capacitance.

Where multiple corrections are required they should be made in the following order: (1) vacuum-tube-voltmeter loading, (2) internal Q-meter impedances, and (3) distributed capacitance, in each step using the semi-corrected values of Q and L for the apparent Q and L in the succeeding correction.

Having considered the errors inherent in our original data as measured on the Q meter, we are in a position to outline the method of obtaining the effective permeability μ and the loss factor ρ for a core sample. With any coil (but for maximum accuracy preferably one the same length as, or shorter than, the core and with moderate wall thickness) determine the apparent Q of the coil in air and with the core, and the capacitance required to resonate the coil under each of these conditions at the chosen test frequency. The necessary corrections may then be applied to these original data to get the true change of inductance and the true change of Q. From the known physical dimensions of the coil and core and knowing the true change of inductance due to the core, the effective permeability of the core may be readily calculated from (7).

The resistance with and without the core is computed from the corrected Q and inductance values, and the difference, the resistance due to the core, is substituted in (14) or (16) to obtain the value of loss factor ρ.

Effect of the Core on Coil Q

The effective permeability and loss factor of a core material furnish fundamental specifications of that material. However, the effect of such a core on the Q of a coil cannot be predicted without a knowledge of the Q of the coil in air. The computation of the Q of a coil in air is not covered in this paper, but rather it is assumed that the coil Q will be known from measurement or experience. With this knowledge, and with a knowledge of the core-material permeability and loss factor, the effect of the core on the coil Q can then be predicted. However, in some instances it may be desired to compare cores by comparing their effects upon the Q's of various coils, without measuring their permeability or loss factors.

It is common knowledge that a given core will cause a greater percentage change in Q when inserted in a coil of high Q than when inserted in a coil of low Q. It is, therefore, apparent that comparing the percentage effects upon coil Q is meaningless unless the coil Q's are initially the same in air, or if the coil Q's are different, unless the data have been corrected for the varying initial Q's in air.

A formula has been developed (see Appendix D) to permit the conversion of core effects upon coil Q, expressed as percentage of Q in air, from any initial Q, Q_0, to any other initial Q, Q_2, and is given below:

$$\beta = \frac{\eta Q_0}{Q_0 + Q_2\left(\frac{\eta}{\alpha} - 1\right)} \tag{24}$$

where,

β = percentage effect on Q, based on coil Q in air of Q_2

η = percentage change in inductance due to core

α = percentage effect on Q, based on coil Q in air of Q_0

Q_0 = an initial coil Q in air for which α is known

Q_2 = a different initial coil Q in air for which β is desired.

The effect of external circuit impedances must also be considered when calculating the effect of a core in a specific application. The data given in this paper have had the effect of all external circuit influences removed, and indeed all such data should be so corrected to permit maximum usefulness. Allowance must be made for external circuit configurations whether the data on the iron are in the form of μ and ρ or in the form of η and α. When the original iron data are in terms of μ and ρ the external circuit effects are simply computed and no formulas will be given for such computations. When the data are in the form of η and α the correction expressions are not immediately apparent hence will be given below. The derivation of these expressions is given in Appendix E.

The expression for the corrected change of inductance when external circuit impedances are present is

$$\theta = \frac{\eta + \gamma}{1 + \gamma} \tag{25}$$

where,

θ = percentage change in inductance with external inductance ΔL_0 in circuit

η = percentage change in inductance due to core, with no external inductances

$\gamma = \Delta L_0 / L_0$, ratio of external inductance to coil inductance in air.

The corrected percentage of Q change when external impedances are present is given by

$$\phi = \alpha \frac{\eta + \gamma}{\eta + \gamma_\psi} \tag{26}$$

where,

ϕ = percentage change in Q referred to Q of coil in air of Q_0, and with external circuit impedances

α = percentage change in Q referred to Q of coil in air of Q_0, and with no external circuit impedances

η = percentage change in inductance due to core

$\gamma = \Delta L_0 / L_0$ ratio of external inductance to coil inductance in air

$\psi = Q_1 / Q_{\Delta 0}$ ratio of coil Q with core to external circuit impedance Q.

Conditions of Measurement

The cores available for experimental work had a minimum length of $\frac{1}{2}$ of an inch. To maintain maximum accuracy and to avoid undue labor in the computation of results it was desirable to have the coil completely filled by the core for all measurements. This consideration dictated a coil length not in excess of $\frac{1}{2}$ of an inch. To obtain a maximum increment of inductance it was desirable to have as long a coil as possible with as thin walls as possible. Thus the test coil length was fixed at $\frac{1}{2}$ of an inch, and the diameter was fixed by a compromise between the maximum inductive increment and the presence of undesired capacitance effects between the core and the coil of a magnitude requiring correction. The final series of test coils used, and shown in Fig. 3, were so proportioned that corrections for capacitive effects were unnecessary.

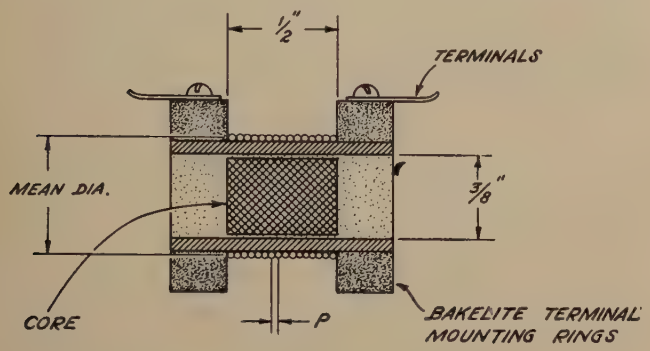
Coil lengths were maintained constant at $\frac{1}{2}$ of an inch and the necessary inductance variations for the various frequencies of measurement were obtained by varying the winding pitch and by the use of an external loading coil in the case of the 0.4-megacycle measurement. The effect of variable winding pitch upon the accuracy of measurement was found to be of second-order importance by computations taking into account the

noncurrent-sheet conditions prevailing with coils of large winding pitch.

Description of Cores Tested

In order to determine the applicability of the expressions derived and to investigate the range of characteristics to be expected, several samples of currently available cores were tested.

In the present state of the art there is no rational basis for designation of commercial core materials by the several manufacturers, each manufacturer having some arbitrary identification which has no physical or electrical significance. Samples of materials having nine different designations were tested. Some of the materials differed but little from others, but there were four rather well-defined groups into which the materials fell. Samples from each of these four groups were accordingly designated as materials A, B, C, and D, respectively.



COIL	MEAN DIA.	P
0.4MC	0.505"	0.00333"
1	0.506"	0.00555"
3	0.516"	0.0179"
9	0.475"	0.0335"
15	0.483"	0.042"
25	0.483"	0.0825"
35	0.483"	0.125"
50	0.483"	0.182"

Fig. 3—Experimental test coil.

All of the samples tested were $\frac{3}{8}$ of an inch in diameter and varied in length from $\frac{1}{2}$ to $1\frac{1}{2}$ inches.

In addition tests were made with a $\frac{3}{8}$-inch-diameter core of commercially pure annealed copper. This has been designated as material E.

The types of cores tested, while representative, do not by any means cover all types currently manufactured. In particular it is felt that there are types of cores current which have higher effective permeability than any included in this series of tests.

For some types of cores, several samples were tested. The variations between cores of the same designation were found to be small, being less than those between different types of the same group.

Performance of Cores

The fundamental performance of a core material is specified by a statement of the effective permeability μ and the loss factor ρ for the material. The determination of μ and ρ may be made with test coils varying within comparatively wide limits without appreciable effects upon the accuracy of the results obtained. Core performance may also be specified as the effect upon coil Q when the inductance of a coil is changed by a specified amount due to the insertion of the core. This method of specification requires an exact statement of coil and core geometry and of the electrical characteristics of the coil, and the results obtained will be valid only for that particular coil and core. Both of these methods have been employed to specify certain typical cores, previously described, as an illustration of the measurement techniques described in this paper.

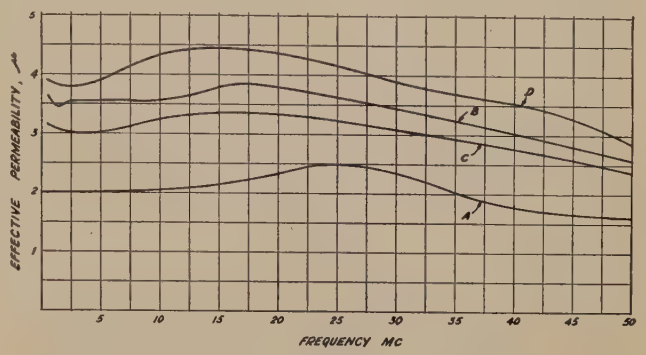


Fig. 4—Effective permeability of 4 types of iron.

Fig. 4 shows the effective permeability μ as a function of frequency. It will be seen that the μ is practically constant below 20 megacycles and falls off at higher frequencies.

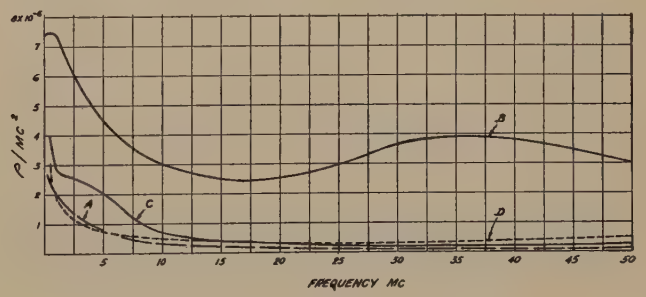


Fig. 5—Loss factor per megacycle-squared of 4 types of iron (length units in inches).

As an interesting side light on the effective permeability of powdered iron cores, Howe[1] has shown that the effective permeability μ of a core is given by

$$\mu = \frac{\mu_1 - 0.667\delta(\mu_1 - 1)}{1 + 0.333\delta(\mu_1 - 1)} \qquad (27)$$

where,

μ_1 = specific permeability of iron particles

δ = the fraction of the core volume occupied by insulating material.

[1] G. W. O. Howe, Editorial, *Wireless Eng.*, January, 1933.

This expression shows that the volume factor δ for the insulating material is of considerably greater importance in determining the effective permeability than is the specific permeability of the iron itself. For example, if the insulating material occupied 10 per cent of the volume ($\delta = 0.1$) iron of infinite permeability would show an effective permeability of only 28 in the core.

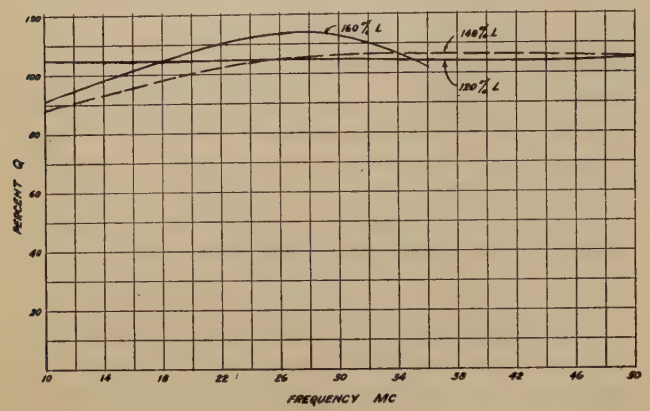


Fig. 6—Per cent Q versus frequency for core A.

Measured in experimental test coil shown in Fig. 3. Data corrected and reduced to initial coil Q_0 of 100.

This shows why finely divided (δ is high) low-loss cores are inherently of low effective permeability.

Fig. 5 shows ρ per megacycle-squared as a function of frequency. The calculation of ρ is based on inches as units of length. Iron B is shown up as an exceptionally high-loss iron. The small ρ per megacycle-squared scale made necessary by iron B makes irons A, C, and D appear to be almost identical. However close inspection shows as much as a 7-to-1 variation in the loss factor

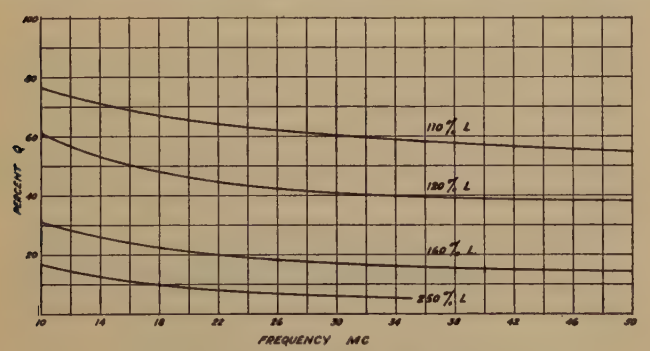


Fig. 7—Per cent Q versus frequency for core B.

Measured in experimental test coil shown in Fig. 3. Data corrected and reduced to initial coil Q_0 of 100.

at 50 megacycles. These characteristics are significant in showing the component contributions of hysteresis and eddy-current losses to the total loss caused by the iron. Above approximately 8 megacycles all characteristics approach straight, flat lines (approximately in the case of iron B), indicating that ρ increases as the square of the frequency and as such is predominantly made up of eddy-current losses which are known to increase according to a square law. At lower frequencies the relatively increased importance of hysteresis losses cause the characteristics to depart from straight-line functions on this chart. We thus arrive at the important conclusion that at frequencies where the eddy-current loss is predominant the factor ρ per megacycle-squared is constant to a good degree of approximation over wide ranges of frequency.

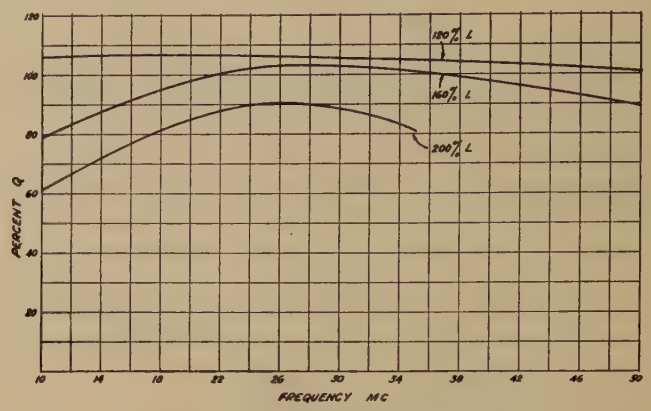


Fig. 8—Per cent Q versus frequency for core C.

Measured in experimental test coil shown in Fig. 3. Data corrected and reduced to initial coil Q_0 of 100.

Although μ and ρ are the fundamental specifications of an iron, curves have been included for illustrative purposes showing the characteristics of iron specified as the effect upon coil Q for stated inductance changes due to the iron. These characteristics are shown in Figs. 6 to 9, inclusive. It is to be reiterated that these characteristics are dependent upon coil and core geometry and upon the coil and core electrical characteristics,

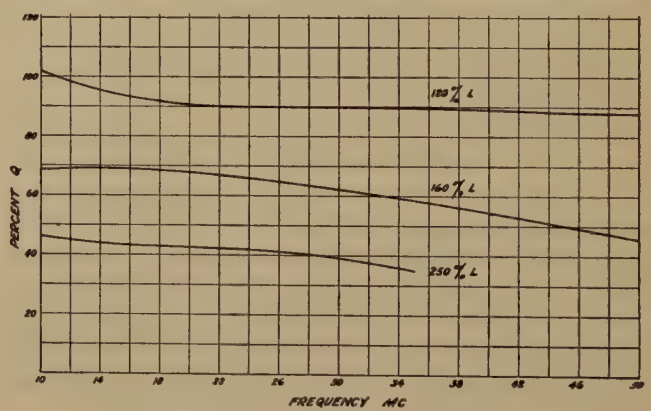


Fig. 9—Per cent Q versus frequency for core D.

Measured in experimental test coil shown in Fig. 3. Data corrected and reduced to initial coil Q_0 of 100.

and are valid only for the stated conditions. These characteristics are completely corrected for all measurement errors and are reduced to a constant initial coil Q of 100. Characteristics of this type are useful principally in determining the effect of relatively small changes of coil or core parameters on the coil Q.

Fig. 10 shows Q characteristics, comparable to those shown in Figs. 6 to 9, for a core of pure copper. These curves indicate the performance of copper improves as

the frequency is raised. They also indicate that where only small inductance changes are desired from a core, that copper compares very favorably with iron in so far as effect upon coil Q is concerned. These characteristics are corrected and are under the same restriction as those shown in Figs. 6 to 9.

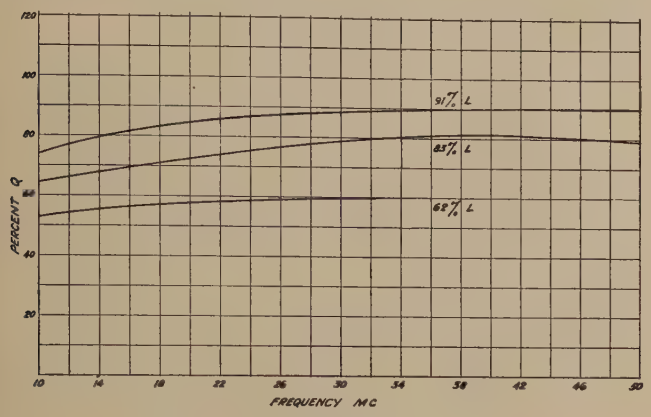


Fig. 10—Per cent Q versus frequency for core E (copper).

Measured in experimental test coil shown in Fig. 3. Data corrected and reduced to initial coil Q of 100.

The effect of the coil diameter upon the inductance increase obtained by an iron core, and the associated change in coil Q, is shown in Fig. 11. These characteristics, obtained by varying the coil diameter while holding all other parameters constant, are of importance in pointing out the direction of optimum coil design. These characteristics are concave upwards with the slope constantly decreasing as the coil diameter de-

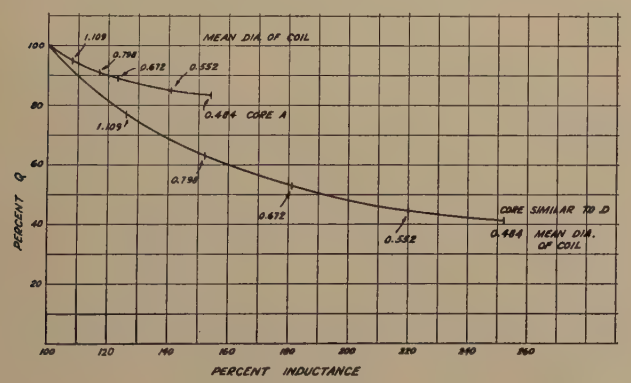


Fig. 11—Variation of per cent Q and per cent inductance with coil diameter.

Frequency = 9 megacycles
Core length = $\frac{3}{4}$ inch
Core diameter = $\frac{3}{8}$ inch
Coil length = 1 inch
Winding pitch = 0.053 inch
Core material = as indicated
Data corrected and reduced to initial coil Q_0 of 100.

creases. This means that increasingly larger amounts of inductance change are obtained with increasingly smaller amounts of Q change, and that, therefore, the most efficient coil design is obtained with the largest ratio of core diameter to coil diameter. The limitation on such increase of efficiency may be the rise of core-to-coil capacitance effects as very thin coil walls are approached. These effects become of first-order importance in long coils with very thin walls such as may be used in the region of 1.0 megacycle.

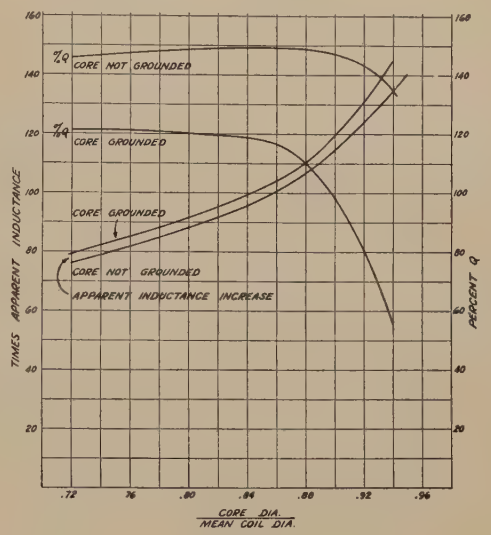


Fig. 12—Core-to-coil-capacitance effects.

Coil length = $1\frac{1}{2}$ inches
Core length = $2\frac{1}{4}$ inches
Initial coil Q_0 = 75
Winding pitch = 0.00855 inch
Tuning capacitance = 233 to 390 micromicrofarads
Core diameter = $\frac{3}{8}$ inch
Core material similar to core D.

Figs. 12 and 13 illustrate the capacitance effects between the core and the coil that may be encountered on long thin-walled coils. The apparent change of in-

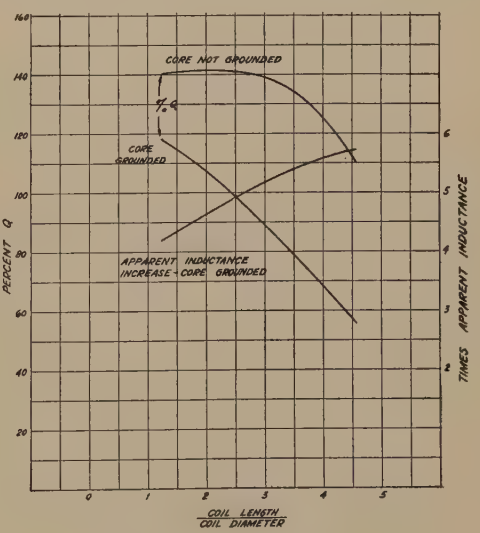


Fig. 13—Core-to-coil-capacitance effects.

Coil length = core length
Initial coil Q_0 = 75
Core diameter = $\frac{3}{8}$ inch
Coil diameter = 0.441 inch
Winding pitch = 0.00700 inch
Tuning capacitance = 100 to 195 micromicrofarads
Core material similar to core D.

ductance and the per cent of initial coil Q in air with the core in the coil is shown in Fig. 12 as a function of core-diameter-to-coil-diameter ratio. The quasi-distributed-capacitance effect of the core is considerably

greater with the core grounded than with the core floating, as is evidenced by the increased apparent inductance change when the core is grounded. The increased coil-to-core capacitance causes a very large drop in coil Q due to the high dielectric losses in the coil form.

Fig. 13 shows the apparent inductance increase and the Q change caused by the core plotted as the function of the coil-length-to-coil-diameter ratio. The rising apparent-inductance-change characteristic shows the effect of increased coil-to-core capacitance as the length of the coil and core is increased. We notice the same deleterious effect upon Q as was noted in Fig. 12 when the core is grounded.

The analytical expression of the capacitance effects just discussed would involve a consideration of external circuit conditions and the dielectric properties of the coil form, and is beyond the scope of this paper.

Conclusions

The characteristics of an iron core may be rationally expressed by measurement of its effective permeability μ and its loss factor ρ.

Given μ and ρ for an iron its effect upon a coil of known physical and electrical characteristics can be predicted with good engineering accuracy.

Various irons may be directly compared in performance with a knowledge of μ and ρ, but if only the effect upon the Q of a coil is known, certain corrections and reductions of data may be necessary before comparisons can be made, and even then the results are valid only for the particular coils used.

The value of ρ per megacycle-squared is substantially constant above frequencies of the order of 8 to 10 megacycles, making interpolation or extrapolation possible with a minimum loss of accuracy.

The value of μ is substantially constant below 8 to 10 megacycles and changes but slowly as the frequency is raised, making reasonably accurate interpolation or extrapolation possible.

Copper cores offer relatively good performance as compared to iron at high frequencies, and for applications where small amounts of inductance change are desired.

To obtain a given inductance change with an iron core the least sacrifice of Q will result when the core diameter is most nearly equal to that of the coil, neglecting coil-to-core capacitance effects.

Coil-to-core-capacitance effects may become appreciable for long coils having thin walls. These effects increase the apparent inductance change caused by the iron and have a deleterious effect upon the coil Q. The effects are least pronounced with the core ungrounded.

Measurement errors due to apparatus limitations must be considered and corrected for if important. Generally speaking, corrections will be required at frequencies above a few megacycles.

Appendix A

The rudiments of the Q meter are shown in Fig. 14. Operation may be briefly described by saying that the Q of coil L is given approximately by the ratio E_1/E_0 when L is tuned to resonance by capacitor C. By keeping E_0 at a known fixed value, the vacuum-tube voltmeter may be calibrated directly in Q.

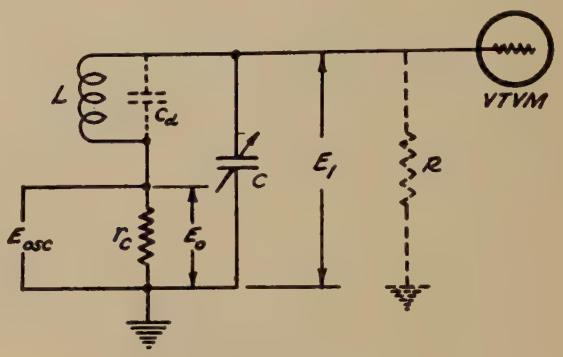


Fig. 14—Elementary Q-meter circuit.

When R is finite an equivalent series resistance will be reflected into the resonant circuit LC resulting in lower apparent coil Q. The series resistance reflected into LC is given by $1/\omega^2C^2R$ when the circuit is at resonance. The apparent circuit resistance in LC is given by $1/\omega CQ_a$ which includes the term $1/\omega^2C^2R$, therefore the true Q of coil L is given by

$$Q = Q_a \frac{\dfrac{1}{\omega CQ_a}}{\dfrac{1}{\omega CQ_a} - \dfrac{1}{\omega^2C^2R}} = Q_a \left(\frac{1}{1 - \dfrac{Q_a}{\omega CR}} \right). \quad (17)$$

Appendix B

The correction for internal resistance r_m is given by

$$Q = Q_a \frac{r_a}{r_a - r_m} = Q_a \left(\frac{1}{1 - \dfrac{r_m}{r_a}} \right) \quad (18)$$

where $r_a = 1/\omega CQ_a$ = apparent circuit resistance.
The correction for internal inductance L_m is given by

$$L = L_a - L_m \quad (19)$$

$$L_a = \frac{25{,}330}{f^2C} \quad (28)$$

L_a = apparent coil inductance in microhenrys with f in megacycles and C in micromicrofarads.

To compute the corrected change of inductance due to the insertion of a core in a coil when there are circuit inductances unaffected by the core, e.g., internal inductance in the Q meter, the true change of inductance η is given by

$$\eta = \frac{L_a' - L_m}{L_a - L_m} \quad (29)$$

where,
L_a' = apparent inductance with core, from (28)
L_a = apparent inductance without core, from (28)
L_m = inductance unaffected by core.
Dividing the numerator and denominator by L_a,

$$\eta = \frac{\frac{L_a'}{L_a} - \frac{L_m}{L_a}}{1 - \frac{L_m}{L_a}} = \frac{\eta_a - \tau}{1 - \tau} \tag{20}$$

where,
$L_a'/L_a = \eta$ = apparent inductance change
$L_m/L_a = \tau$ = ratio of external inductance to apparent inductance of coil without core.

Appendix C

The apparent resistance and inductance of a coil with distributed capacitance is given by[2]

$$r_a = \frac{r}{(k^2 - 1)^2} \tag{30}$$

$$L_a = \frac{L}{-(k^2 - 1)} \tag{31}$$

when k^2 is small.

Note: Equation (31) is true only for $k < 1$. For $k < 1$ the combination will look like a capacitance.

The apparent Q, Q_a is given by

$$Q_a = \frac{\omega L_a}{r_a} = \frac{-\omega L}{r} \cdot \frac{(k^2 - 1)^2}{k^2 - 1} = -Q(k^2 - 1) \tag{32}$$

where,
Q = true Q of coil
$k = f/f_0$,
f_0 = resonant frequency of coil with its distributed capacitance C_d.
Now,

$$k^2 = \frac{f^2}{f_0^2} = \frac{4\pi^2 LC_d}{4\pi^2 LC} = \frac{C_d}{C} \tag{33}$$

therefore,

$$Q = \frac{Q_a}{1 - k^2} = Q_a \left(\frac{1}{1 - \frac{C_d}{C}} \right). \tag{23}$$

The expressions for r and L, (21) and (22), may be derived by substituting (33) in (30) and (31), respectively.

Appendix D

To derive the conversion expression for the effect of changing the initial coil Q in air upon the percentage change of Q caused by a core, refer to Figs. 15 and 16 and to the derivation below. The nomenclature adopted is given below, immediately preceding the derivation.

r_0 = resistance, in air, of coil for which effect of core on Q is known
r_1 = resistance, with core, of coil for which effect of core on Q is known

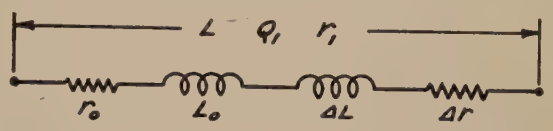


Fig. 15—Coil upon which the effects of core are known.

r_2 = resistance, in air, of coil for which effect of core on Q is desired
r_3 = resistance, with core, of coil for which effect of core on Q is desired
Δr = resistance added to either coil by core
ΔL = inductance added to either coil by core
L_0 = inductance of either coil in air
L = inductance of either coil with core
$Q_0 = Q$, in air, of coil upon which the effect of core is known
$Q_1 = Q$, with core, of coil upon which the effect of core is known
$Q_2 = Q$, in air, of coil upon which the effect of core is desired
$Q_3 = Q$, with core, of coil upon which the effect of core is desired
$\eta = L/L_0$ percentage change in inductance due to core
$\alpha = Q_1/Q_0$ percentage effect on Q based on coil Q in air of Q_0
$\beta = Q_3/Q_2$ percentage effect on Q based on coil Q in air of Q_2.

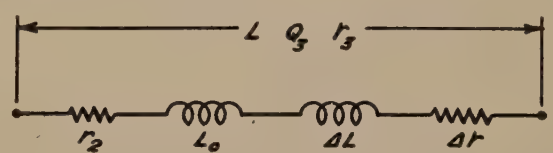


Fig. 16—Coil upon which the effects of core are desired.

$$\alpha = \frac{Q_1}{Q_0} = \frac{\omega L}{r_1} \cdot \frac{r_0}{\omega L_0} = \frac{L r_0}{L_0 r_1} \tag{34}$$

$$\beta = \frac{Q_3}{Q_2} = \frac{\omega L}{r_3} \cdot \frac{r_2}{\omega L_0} = \frac{L r_2}{L_0 r_3}. \tag{35}$$

Substituting (34) in (35) and rearranging,

$$Q_3 = \frac{Q_1 Q_0}{Q_0} \cdot \frac{r_1 r_2}{r_0 r_3} \tag{36}$$

$$\Delta r = \frac{\omega L}{Q_1} - \frac{\omega L_0}{Q_0} \tag{37}$$

$$r_2 = \frac{\omega L_0}{Q_2} \tag{38}$$

$$r_3 = r_2 + \Delta r = \frac{\omega L_0}{Q_2} + \frac{\omega L}{Q_1} - \frac{\omega L_0}{Q_0} \tag{39}$$

[2] John H. Morecroft, "Principles of Radio Communication," second edition, John Wiley and Sons, Inc., New York, N. Y., 1927, p. 91.

$$r_1 = \frac{\omega L}{Q_1} \tag{40}$$

$$r_0 = \frac{\omega L_0}{Q_0}. \tag{41}$$

Substituting (38), (39), (40), and (41) in (36) and simplifying,

$$Q_3 = \frac{Q_0 Q_1 Q_2 L_0 L}{L_0(L_0 Q_0 Q_1 + L Q_0 Q_2 - L_0 Q_1 Q_2)}. \tag{42}$$

Dividing the numerator and denominator by $L_0^2 Q_1$,

$$Q_3 = \frac{Q_0 Q_2 \dfrac{L}{L_0}}{Q_0 + \dfrac{L}{L_0}\cdot\dfrac{Q_0 Q_2}{Q_1} - Q_2}.$$

Expressing Q_3 as a percentage of Q_2, and substituting η for L/L_0 and α for Q_1/Q_0,

$$\frac{Q_3}{Q_2} = \beta = \frac{\eta Q_0}{Q_0 + Q_2\left(\dfrac{\eta}{\alpha} - 1\right)}. \tag{24}$$

Appendix E

To derive the correction expressions for the effect of external circuit impedances, reference is made to Fig.

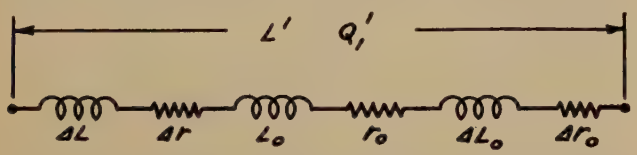


Fig. 17—Coil with core and with external circuit impedance.

17. The nomenclature used in Appendix D is retained and the following additions made.
ΔL_0 = external inductance in circuit
Δr_0 = external resistance in circuit
Q_1' = Q of coil with core and with external impedances
$Q_{\Delta 0}$ = Q of external circuit impedance.
To compute the net inductance change with inductance external to the coil in the circuit, we have,

$$\frac{L'}{L_0 + \Delta L_0} = \theta = \frac{L_0 + \Delta L + \Delta L_0}{L_0 + \Delta L_0} \tag{43}$$

$$\theta = \frac{1 + \dfrac{\Delta L}{L_0} + \dfrac{\Delta L_0}{L_0}}{1 + \dfrac{\Delta L_0}{L_0}} \tag{44}$$

$$1 + \frac{\Delta L}{L_0} = \frac{L}{L_0} = \eta.$$

Let

$$\frac{\Delta L_0}{L_0} = \gamma$$

$$\theta = \frac{\eta + \gamma}{1 + \gamma}. \tag{25}$$

Computing the effect of external impedance upon the percentage change of Q we have

$$\frac{Q_1'}{Q_1} = \frac{L_0 + \Delta L + \Delta L_0}{r_0 + \Delta r + \Delta r_0}\cdot\frac{r_0 + \Delta r}{L_0 + \Delta L} \tag{45}$$

$$= \frac{1 + \dfrac{\Delta L}{L_0} + \dfrac{\Delta L_0}{L_0}}{1 + \dfrac{\Delta L}{L_0}}\cdot\frac{r_0 + \Delta r}{r_0 + \Delta r + \Delta r_0} \tag{46}$$

$$1 + \frac{\Delta L}{L_0} = \frac{L}{L_0} = \eta$$

$$\frac{\Delta L_0}{L_0} = \gamma$$

$$\frac{Q_1'}{Q_1} = \frac{\eta + \gamma}{\eta}\cdot\frac{r_0 + \Delta r}{r_0 + \Delta r + \Delta r_0}. \tag{47}$$

Considering the last term of (47) and stating the r's in terms of L and Q we have

$$\frac{r_0 + \Delta r}{r_0 + \Delta r + \Delta r_0} = \frac{\dfrac{\omega(L_0 + \Delta L)}{Q_1}}{\dfrac{\omega(L_0 + \Delta L)}{Q_1} + \dfrac{\omega \Delta L_0}{Q_{\Delta 0}}}. \tag{48}$$

Multiplying the numerator and denominator through by $Q_1/\omega L_0$,

$$\frac{r_0 + \Delta r}{r_0 + \Delta r + \Delta r_0} = \frac{1 + \dfrac{\Delta L}{L_0}}{1 + \dfrac{\Delta L}{L_0} + \dfrac{\Delta L_0}{L_0}\cdot\dfrac{Q_1}{Q_{\Delta 0}}}$$

$$= \frac{\eta}{\eta + \gamma\dfrac{Q_1}{Q_{\Delta 0}}}. \tag{49}$$

Substituting (49) in (47) and calling

$$\frac{Q_1}{Q_{\Delta 0}} = \psi,$$

$$\frac{Q_1'}{Q_1} = \phi = \frac{\eta + \gamma}{\eta}\cdot\frac{\eta}{\eta + \gamma\psi} = \frac{\eta + \gamma}{\eta + \gamma\psi} \tag{50}$$

$$\frac{Q_1'}{Q_0} = \frac{Q_1}{Q_0}\cdot\frac{\eta + \gamma}{\eta + \gamma\psi} = \alpha\frac{\eta + \gamma}{\eta + \gamma\psi}. \tag{26}$$

Undercoupling in Tuned Coupled Circuits to Realize Optimum Gain and Selectivity*

J. J. ADAMS†, ASSOCIATE, I.R.E.

Summary—*Setting the coupling of intermediate-frequency transformers below the critical value gives an increase in skirt selectivity without much loss of gain. If the coupling is set too far below the critical value more gain is lost than selectivity is gained. It is desirable to be able to set the units to get the best gain and selectivity. The mathematical analysis gives an indication of what can be done to get this condition without considerable trial-and-error work.*

IN THE design of household receivers, the coupling in the intermediate-frequency transformers is usually made less than critical. One reason is that if the transformers are set to the critical value, production variations will make some of them overcoupled. Also, skirt selectivity can be increased without much loss in over-all gain. If the coupling is too far below the critical value, the loss in gain will be more than the gain in skirt selectivity. Also the band width on the nose will be made too narrow. We shall assume, to start with, that the nose selectivity will not be decreased too much by slight undercoupling. Then, if gain and skirt selectivity are of equal importance, it can be demonstrated that the maximum ratio of gain to skirt selectivity can be procured by making the coupling about 80 per cent of the critical value. If the gain is the more important of the two, the maximum ratio will come at a coupling nearer the critical value. If the selectivity is the more important, the maximum ratio will come at a coupling less than 80 per cent of the critical value.

Many engineers use the figure of $W_{10}/W_2=2.5$, which is about 80 per cent of the critical value. In practical units, looser coupling than this cuts the nose selectivity too much. Tighter coupling helps gain only slightly. The band width on the nose is larger, but in most sets broad-nose intermediate frequencies are not necessary. For these reasons the case of equal importance for gain and selectivity is treated. With these and other assumptions we get an optimum coupling at 81.6 per cent of the critical value.

In actual design, it is necessary to have figures on selectivity that can be used in the laboratory. A well-known figure is W_{10}/W_2 (band width at 10 times down divided by band width at 2 times down). Another figure to be used here is W_{100}/W_4 (band width at 100 times down divided by band width at 4 times down). From the equations to be derived it can be found that for a single stage of intermediate frequency, $W_{10}/W_2=\sqrt[4]{33}=2.52$ approximately for the above optimum coupling (81.6 per cent of the critical value), $W_{10}/W_2=2.4$ approximately at the critical value, $W_{10}/W_2=3$ for zero coupling (cascaded circuits). To design a two-stage intermediate frequency with the above optimum coupling, adjust the coupling of the second intermediate-frequency transformer until W_{10}/W_2 (measured at the intermediate-frequency grid) $=2.52$. Then with the intermediate-frequency grid biased back enough to eliminate regeneration, adjust the coupling of the first intermediate-frequency transformer until W_{100}/W_4 (measured at the converter grid) $=2.52$. Both units will then be set to this optimum coupling. Stabilization should then be added to the circuit until the stage gain (converter to intermediate-frequency grid) is the same (or nearly so) without the intermediate-frequency grid biased. This method can be used for any other value of coupling. It works very well in practice and eliminates the trial-and-error method of deriving coupling optimum for gain and selectivity.

To obtain these equations and values it is necessary first to derive the selectivity curves for a single stage of tuned coupled circuits. Couplings other than mutual are not taken into account.

Definitions

$$f_0=\frac{\omega_0}{2\pi}=\frac{1}{2\pi\sqrt{L_1C_1}}=\frac{1}{2\pi\sqrt{L_2C_2}},$$

the resonant frequency to which both circuits are tuned.

$$f_1=\frac{\omega_1}{2\pi}=\text{frequency off resonance}$$

$$Q_1=\frac{\omega_0L_1}{r_1};\ Q_2=\frac{\omega_0L_2}{r_2},$$

the Q of primary and secondary circuits, including loading effect of tubes (all Q's are assumed to be independent of frequency over the frequency range considered).

$$Q=\sqrt{Q_1Q_2},\ \text{mean } Q \text{ of the stage}$$

$$Y=\frac{\text{gain at resonance}}{\text{gain at any frequency}}=\text{attenuation.}$$

This is the dependent variable used.

$$X=Q\frac{f_1}{f_0}\ \text{is the independent variable used.}$$

$K=$ ratio of coupling to that which is critical

$$=\frac{\omega_0M}{\sqrt{r_1r_2}}=CQ\left(C=\frac{M}{\sqrt{L_1L_2}}\right)$$

* Decimal classification: R142.3×R361. Original manuscript received by the Institute, November 1, 1940; revised manuscript received, February 27, 1941.

† Zenith Radio Corporation, Chicago, Ill.

($K=1$ at critical). This is the parameter to be used. From circuit theory

$$\frac{E_2}{E_1} = \frac{\mu\omega_0 M}{R_p\omega_0^2 C_1 C_2\sqrt{A}}$$

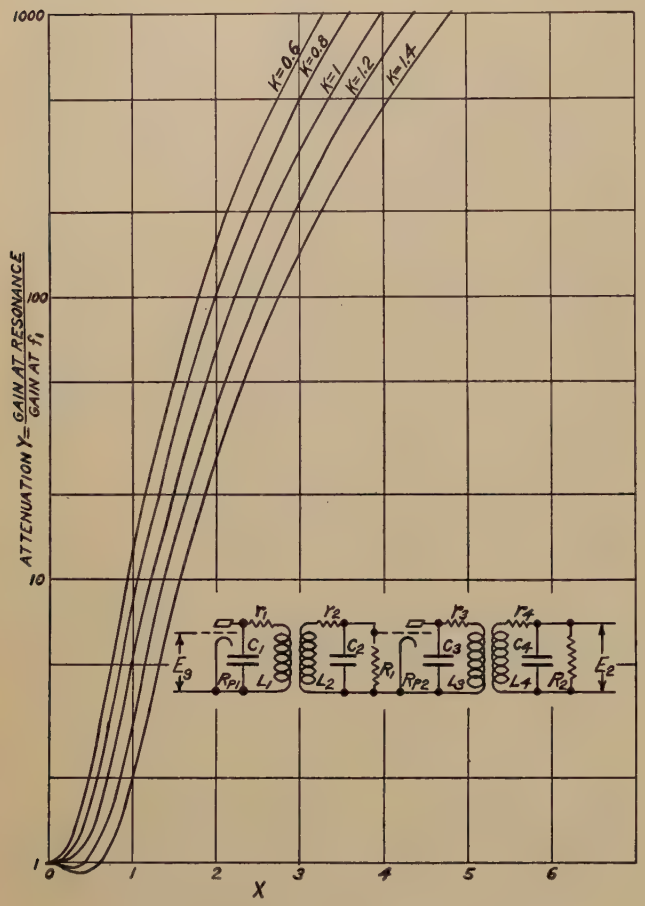


Fig. 1—Calculated selectivity curves for two stages of intermediate-frequency amplification. $X=Qe(f_1/f_0)$.

where

$$A=(r_1r_2+\omega^2M^2)^2+r_1^2\left(\omega L_2-\frac{1}{\omega C_2}\right)^2+r_2^2\left(\omega L_1-\frac{1}{\omega C_1}\right)^2$$
$$-2\omega^2M^2\left(\omega L_1-\frac{1}{\omega C_1}\right)\left(\omega L_2-\frac{1}{\omega C_2}\right)$$
$$+\left(\omega L_1-\frac{1}{\omega C_1}\right)^2\left(\omega L_2-\frac{1}{\omega C_2}\right)^2.$$

By assuming that

$$\frac{2\omega_0+\omega_1}{\omega_0+\omega_1}=2 \text{ and that } \frac{Q_1+Q_2}{2}=\sqrt{Q_1Q_2}$$

in one term, after a number of steps we obtain the following:

$$\frac{E_2}{E_1}=\frac{\mu\omega_0\sqrt{L_1L_2}\,Q\,K}{R_p\sqrt{(4X^2+1-K^2)^2+4K^2}}.$$

Take

$$Y^2=\frac{(4X^2+1-K^2)^2+4K^2}{(1+K^2)^2}$$

(when $X=O$, resonance, $Y=1$).

This equation gives the selectivity curves for different values of K. To get band width at Y times down solve for X in terms of Y. Then

$$\left|\frac{E_2}{E_1}\right| = \text{gain} = \frac{\mu\omega_0\sqrt{L_1L_2}\,Q}{RpY}\cdot\frac{K}{1+K^2}.$$

Two main assumptions were made. The first is that

$$\frac{2\omega_0+\omega_1}{\omega_0+\omega_1}=2.$$

This is justified near the resonant frequency but gives an error in selectivity on the skirts of the curve. A correction factor of $(2Q+X)/(2(Q+X))$ can be used for Y greater than 30. The other is that Q_1 and Q_2 are nearly equal.

Fig. 1 gives the selectivity of two stages of tuned coupled circuits.

$$Y=\frac{(4X^2+1-K^2)^2+4K^2}{(1+K^2)^2} \text{ where } X=Q\frac{f_1}{f_0} \text{ and}$$

$$Q=\sqrt[4]{Q_1Q_2Q_3Q_4}$$

$$K=\sqrt{K_1K_2} \text{ (good for } K_1 \text{ and } K_2 \text{ nearly equal)}$$

$$\text{the gain} = \frac{\mu_1\mu_2\omega_0^2\sqrt[4]{L_1L_2L_3L_4}\,Q}{R_{p1}\,R_{p2}\,Y}\cdot\frac{K^2}{(1+K^2)^2}.$$

The assumption that

$$\frac{2\omega_0+\omega_1}{\omega_0+\omega_1}=2$$

causes no great errors on these curves.

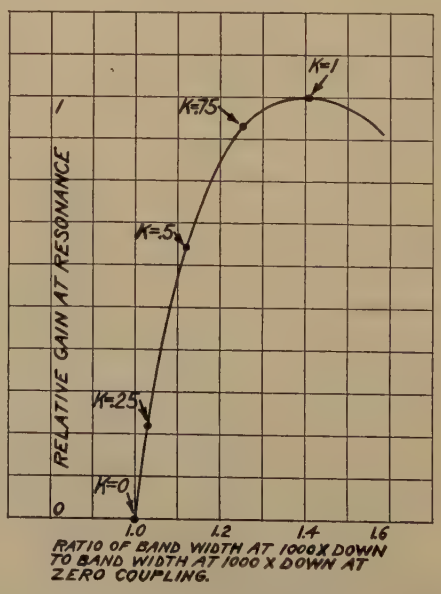


Fig. 2—Curve of gain versus selectivity for two stages of intermediate-frequency amplification.

We now use these last two equations to find an optimum coupling for intermediate-frequency units.

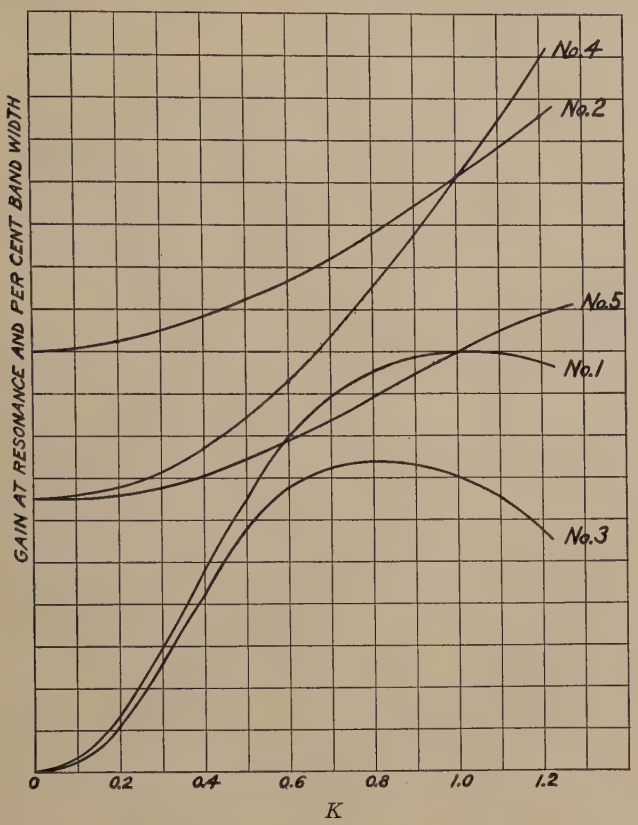


Fig. 3.—Curves of gain, selectivity, and ratio of gain to selectivity versus coupling for two stages of intermediate-frequency amplification.
K = ratio of coupling to the critical value
No. 1—Gain at resonance
No. 2—Per cent band width at 1000 times down
No. 3—Ratio of gain at resonance to per cent band width at 1000 times down
No. 4—Per cent band width at 2 times down
No. 5—Ratio of band width at 2 times down to that at 1000 times down

In Fig. 2 there is shown a graph of gain at resonance against band width at 1000 times down for two stages of intermediate frequency. The parameter K varies along the curve. A few values of K are indicated on the curve. Notice that the gain at resonance changes slowly to the left of the maximum point ($K=1$) of the curve while the band width at 1000 times down changes rapidly. To find a point at which the ratio of gain at resonance to band width at 1000 times down is a maximum the curves of Fig. 3 are plotted. Curve No. 1 is gain at resonance against coupling. Curve No. 2 is band width at 1000 times down against coupling. Curve No. 3 is the ratio of gain to band width at 1000 times down against coupling. By setting the derivative in the equation of this curve equal to zero, a maximum on this curve at $K=0.816$ is obtained. The gain at resonance has decreased about 5 per cent while the band width at 1000 times down has decreased about 10 per cent. At the same time the nose selectivity is hurt by being reduced about 20 per cent. If it is necessary to have better nose selectivity than this, the coupling must go back toward critical. The band width at 2 times down and its ratio to band width at 1000 times down are plotted in curves No. 4 and 5 of Fig. 3. The per cent change in band width at 2 times down is greater than at 1000 times down as the coupling changes.

This mathematical analysis gives a figure for optimum coupling which appears to be quite accurate in practice. It involves a number of assumptions, but they are fairly accurate.

Acknowledgment

The possibility of a noncritical optimum coupling below critical was suggested by Mr. Benin of the Zenith Engineering Department.

Institute News and Radio Notes

Expedited Procedure for Handling Membership Applications

The Institute has recently made a number of significant changes in the system used to handle new applications for membership. These are incorporated in a series of new Bylaws to the Constitution adopted at the May 7 meeting of the Board of Directors, and are given in full in the report of that meeting. However, because of their importance in connection with the recruiting of new members it is felt that a supplementary discussion is desirable.

Applications for nonvoting grades of membership (Associate, Junior, and Student) will now be acted upon within one month of the time of arrival at Institute Headquarters, and such new members will be placed on the mailing list for the PROCEEDINGS immediately upon admission to membership and receipt of entrance fee and dues. Applicants for the grade of Member will also be placed upon the mailing list for the PROCEEDINGS immediately upon the receipt of the application, when an entrance fee is included.

Under the new procedures, a man who decides to join the Institute can receive a return in the form of the PROCEEDINGS within approximately one month from the date of his decision. This brings him into the Institute's sphere of influence while his enthusiasm is a maximum. In contrast, previous practices allowed a "cooling-off" period of at least three months during which interest naturally died down, and which not infrequently caused applicants to become impatient with the Institute.

The full advantage of the present arrangement is obtained only when applications for nonvoting grades are accompanied by the entrance fee and dues, and applications for the grade of Member are accompanied by the entrance fee. It is suggested that those engaged in membership activities make it a special point to see that prospective members realize this fact.

Frederick Emmons Terman
President

Board of Directors

The regular monthly meeting of the Board of Directors was held on May 7 and attended by Haraden Pratt, chairman; Austin Bailey, A. B. Chamberlain, I. S. Coggeshall, Melville Eastham, Alfred N. Goldsmith, Virgil M. Graham, O. B. Hanson, R. A. Heising, L. C. F. Horle, C. M. Jansky, Jr., F. B. Llewellyn, B. J. Thompson, H. M. Turner, A. F. Van Dyck, H. A. Wheeler, L. P. Wheeler, and H. P. Westman, secretary.

Further consideration was given to the questionnaires which are to be distributed to the membership to provide information for a yearbook to be published early in 1942 and to inform the Board of Directors regarding the viewpoints of the membership on various subjects.

A. F. Van Dyck was nominated as the Board's sole candidate for the presidency of the Institute for 1942.

W. A. Rush was named the Board's only candidate for the vice presidency for 1942.

Each year, three Directors are elected to serve for three-year terms. The Board placed six names in nomination for balloting for those to take office next year. These nominees are: A. B. Chamberlain, I. S. Coggeshall, W. L. Everitt, F. R. Lack, B. J. Thompson, and P. C. Sandretto.

Section 5 of the Bylaws was modified to read as follows:

"The name of each applicant for admission or transfer to the grade of Member shall be posted in the PROCEEDINGS after approval by the Admissions Committee."

COMING MEETINGS

Emporium Section
Summer Seminar
August 1 and 2, 1941

Pacific Coast Convention
Seattle, Washington
August 20, 21, and 22, 1941

The following five new Bylaws were adopted and are to be inserted between the existing Sections 6 and 7.

"Sec. 6.1.—The name of each newly admitted or transferred Associate or Member shall be published in the PROCEEDINGS.

"Sec. 6.2.—Dues shall be payable by a newly admitted member beginning with the quarter next succeeding the date of his admission.

"Sec. 6.3.—The name of each applicant for admission to the Institute, except in the case of Member grade, shall be placed on the mailing list for the PROCEEDINGS immediately upon admission to membership and the receipt of his entrance fee and dues.

"Sec. 6.4.—The name of each applicant for admission to the grade of Member shall be placed on the mailing list for the PROCEEDINGS immediately upon receipt of his application and the entrance fee.

"Sec. 6.5.—PROCEEDINGS will be sent to members for a period not shorter than that covered by the payment of dues. Upon request, a newly admitted member may receive the PROCEEDINGS for previous quarters of the current year provided dues are remitted for such additional period."

There were transferred to Member grade R. V. Beshgetoor, L. T. Bourland, P. J. Larsen, H. K. Morgan, T. L. Rowe, and L. C. Simpson. In addition, the following were admitted to Member grade: L. M. Klenk, A. L. Nelson, G. E. Pray, and E. G. Stokes.

Applications numbering 133 for Associate, 9 for Junior, and 96 for Student were approved. This number of elections is larger than normal and results from the adoption of the new Bylaws given above.

Election Notice

Article VII, Section 1, of the Institute's Constitution is reprinted below as it contains all the information pertinent to the election of officers and directors. Following it will be found the names of the candidates nominated by the Board of Directors to be balloted on this year.

"On or before July first of each year, the Board of Directors shall submit to qualified voters a list of nominations containing at least one name each for the office of President and Vice President and at least six names for the office of elected Director and shall call for nominations by petition.

"Nominations by petition may be made by letter to the Board of Directors setting forth the name of the proposed candidate and the office for which it is

desired he be nominated. For acceptance a letter of petition must reach the executive office before August fifteenth of any year and shall be signed by at least thirty-five voting members.

"Each proposed nominee shall be consulted and if he so requests his name shall be withdrawn. The names of proposed nominees who are not eligible under the Constitution shall be withdrawn by the Board.

"On or before September first, the Board of Directors shall submit to the voting members as of August fifteenth, a list of nominees for the offices of President, Vice President, and elected Director, the names of the nominees for each office being arranged in alphabetical order. The ballots shall carry a statement to the effect that the order of the names is alphabetical for convenience only and indicates no preference.

"Voting members shall vote for the candidates whose names appear on the list of nominees, by written ballots in plain sealed envelopes, enclosed within mailing envelopes marked "Ballot" and bearing the member's written signature. No ballots within unsigned outer envelopes shall be counted. No votes by proxy shall be counted. Only ballots arriving at the executive office prior to October twenty-fifth shall be counted. Ballots shall be checked, opened, and counted under the supervision of the Tellers Committee between October twenty-fifth and the first Wednesday in November. The result of the count shall be reported to the Board of Directors at its first meeting in November and the nominees for President and Vice President and the three nominees for Director receiving the greatest number of votes shall be declared elected. In the event of a tie vote the Board shall choose between the nominees involved."

For President—1942

A. F. Van Dyck

For Vice President—1942

W. A. Rush

For Directors—1942–1944

A. B. Chamberlain	F. R. Lack
I. S. Coggeshall	B. J. Thompson
W. L. Everitt	P. C. Sandretto

Executive Committee

A meeting of the Executive Committee was held on May 7, 1941, and attended by Haraden Pratt, chairman; Melville Eastham, Alfred N. Goldsmith, R. A. Heising, B. J. Thompson, and H. P. Westman, secretary.

A request from the Chicago Section for authorization to participate in an Associated Defense Committee being established in that city was approved.

The Secretary was authorized to include the names of Institute Representatives in the published committee lists which appear in the April and October issues of the PROCEEDINGS.

A number of detailed changes were made in the personnel of committees and the list of Institute Representatives.

The Executive Committee prepared the agenda for the meeting of the Board of Directors on the same date and thus considered all of the matters which were placed before the Board. The items enumerated above were handled directly by the Executive Committee on the basis of authority granted to it by the Board of Directors.

Buenos Aires Section Library

We have been informed that through the generosity of A. M. Stevens, a Fellow of the Institute located in the Buenos Aires section, the library of that section has been the recipient of fifteen volumes of back issues of the PROCEEDINGS in addition to a substantial number of volumes and copies of other radio technical journals. Such a collection is believed to be particularly useful to radio engineers of the section.

Sections

Atlanta

Ben Akerman and J. M. Comer, Jr., reviewed a number of papers which were presented recently at the Broadcast Engineering Conference at Ohio State University.

The first speaker covered the following subjects: "Studio Acoustics," "Frequency Reallocation of Broadcast Stations," "Color Television," "Frequency-Modulation Receivers," "Ultra-High-Frequency Antennas and Transmission Lines" and gave information relative to the site location of a frequency-modulation transmitter.

It was pointed out in connection with the reallocation problem that high-power stations with directional antennas and large frequency shifts have priority in the matter of obtaining crystals from the manufacturers. A method of color television, in which the picture appears brighter, was briefly explained. A description was given of an ultra-high-frequency antenna in which horizontal loops are used as elements in place of dipoles as ordinarily used, the advantage of this construction being that there is no coupling between elements. It is advantageous to feed each element of such an antenna by a separate transmission line. The insulation of such transmission lines was discussed.

A paper by Dr. Fletcher of the Bell Telephone Laboratories indicating the upper limit of high-fidelity receivers at about 8500 cycles was also reviewed.

Mr. Comer spoke on receivers. He pointed out that it cost approximately $7.50 to convert an amplitude-modulation receiver to a frequency-modulation type, but that merchandising and other costs bring the increase to the public to about $25.00. In the design of frequency-modulation receivers, a gain in the intermediate-frequency amplifier of 60 decibels can be utilized in contrast with the limit of 50 decibels for amplitude-modulation receivers. The use of baffles to improve loudspeaker reproduction was also discussed.

February 28, 1941, P. C. Bangs, presiding.

"A Round-Table Discussion on Problems Brought About by the Frequency Reallocation of Broadcast Stations" was led by J. M. Comer, Jr. The subject was introduced with a brief review of the various conferences which led to the reallocation of broadcast stations of the United States, Canada, and Mexico. The discussion included the views of both the broadcaster and the serviceman.

From the broadcaster's viewpoint, the securing of crystals for the transmitters and frequency monitors is a major problem. The Federal Communications Commission has co-operated by allowing the installation of crystals in oscillators without their being sealed. The serviceman faces the problem of readjusting some ten million push-button receivers. It was also pointed out that the broadcast band had been extended to 1600 kilocycles.

It was brought out by some of the servicemen present that many receivers do not retain their tuning adjustments. Criticism was made of the engineering of some of the supposedly modern sets. Another suggestion was that the broadcasters acquaint the public with the problem of frequency change-over by spot announcements.

The meeting closed with a discussion of local noise problems caused by power-distribution systems and trolley lines.

March 28, 1941, A. W. Shropshire, chairman, presiding.

Baltimore

A paper on "Design and Development of a Lateral Crystal Recording Head" was presented by F. W. Stellwagen, chief engineer of the electrical division of Fairchild Aviation Corporation.

The original invention of sound recording is credited to Thomas Edison, who in 1876 made hill-and-dale impressions on a metal-foil cylinder. The disk record appeared about twenty years later and was followed by the lateral method of recording. In 1926 the orthophonic system was introduced and improvements were made in the driving unit of the disk cutter. About 1928, instantaneous recordings came into use and four years later the plastic lacquer-coated disks were introduced.

In the so-called constant-energy method of lateral cutting, the product of amplitude and frequency is a constant. Typical amplitudes are 0.016 inch at 50 cycles and 0.00175 inch at 8000 cycles. On 16-inch disks, with 0.037-inch groove spacing, the available $4\frac{3}{4}$ inches of space permits 115 grooves which, at a speed of 33 revolutions per minute, allows 3.44 minutes of record running time.

In constant-amplitude recording, the energy level represented by the maximum lateral velocity of the stylus diminishes by 6 decibels per octave as the frequency decreases. In the orthoacoustic method, frequencies below 100 cycles and above 2000 cycles are emphasized. The point at which there is a variation from one system to another is called the cross-over frequency.

Factors which affect the cross-over frequency are groove spacing, background

noise particularly at small disk diameter, turntable rumble noise, and higher attenuation of high frequencies with a decrease in record diameter. The danger of groove cutover and the reduced energy response level at lower frequencies leads to a selection of constant-amplitude cut superimposed with a constant-velocity cut below 800 cycles.

In a crystal cutter, the displacement is proportional to the applied voltage. The inertia force of a crystal is a function of the crystal moment of inertia, the square of the frequency, and the amplitude. The voltage applied to the crystal then must overcome crystal stiffness, inertia, and damping force of the material being cut. A dip in the resultant characteristic around 4200 cycles is usually smoothed by a pad in the crystal chuck. Crystals normally operated between 60 and 80 degrees Fahrenheit have a peculiar drooping of response of $\frac{1}{2}$ decibel per degree Fahrenheit above 80 degrees. This can be corrected by a capacitive network.

April 18, 1941, Ferdinand Hamburger, chairman, presiding.

Boston

A paper on "Networks with Electrical Symmetry"" was given by E. S. Purington, of the Hammond Research Corporation.

It was shown that the sending current and the received current of a symmetrical bisectable system resulting from a driving force seated in the sending arm are half the vector sum and half the vector difference, respectively, of the current that would flow in the sending arm if the system were closed at the center of symmetry and the current that would flow in the sending arm if the system were opened at the center of symmetry. The insertion-effects equations and the sending-arm load equation developed from this theorem were used in presenting the basic facts of wave-filter and transmission-line performance. Consideration was given to the insertion-loss performance of composite filters with and without structural symmetry, with especial reference to nondissipative low-pass composites terminated by pure ohmic resistances.

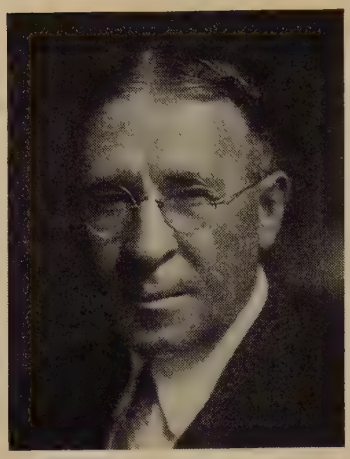
November 29, 1940, W. L. Barrow, chairman, presiding.

W. P. Mason of Bell Telephone Laboratories presented a paper on "New Quartz-Crystal Cuts and Their Application to Oscillators and Filters."

The author discussed the principal types of quartz-crystal cuts and showed how orientation had been employed in obtaining single-resonant crystals and crystals with low temperature coefficients. The applications of single-resonant crystals to filter structures were described and typical characteristics were shown for filters used on the high-frequency coaxial system and short-wave single-sideband radio systems.

Existing low-coefficient crystals were described. These crystals are zero coefficient at one temperature only. The new GT crystal has not only a zero first derivative of frequency with respect to temperature but also a zero second derivative. As a result, it has a very small frequency change over a wide temperature range. The application of this crystal to frequency standards was discussed, and the results obtained with these crystals in the Bell System frequency standard were described.

December 20, 1940, W. L. Barrow, chairman, presiding.



A. A. Hebert

Arthur Aubin Hebert, treasurer of the American Radio Relay League, died on April 3, 1941.

Mr. Hebert was born in 1873 in Quebec. He was educated at the College St. Jean in St. Jean, Quebec. After serving as a railroad telegrapher, he entered the steel industry where he was occupied with sales and administrative work. In 1923, he joined the staff of the American Radio Relay League as treasurer and field man. As field man, he traveled almost constantly for about a dozen years and was acquainted with thousands of amateurs throughout the country. He maintained his financial duties with the League up to the time of his death.

Mr. Hebert was a charter member of the Institute, joining as an Associate in 1912. He transferred to Member grade in 1926.

Buenos Aires

A visit was made to the "Cuyo" Automatic Telephone Exchange of the Compañía Unión Telefónica del Río de la Plata and the radio, telephone, and telegraph terminals of the Compañía Internacional de Radio Argentina.

The Cuyo Exchange is the largest interurban exchange in the southern hemisphere, handling a total of 15,500 automatic lines. It is also the terminal for 301 long-distance telephone circuits with a daily average of 9000 calls originating there to 872 towns in Argentina and, in normal times, 73 foreign countries. There are 103 long-distance boards, 7 international, and 4 radiotelephone boards.

Interest was shown in the long-distance dialing between Buenos Aires, Mar del Plata, La Plata, and other points.

The international radiotelephone terminals were observed in detail. Especial interest was given to the secrecy equipment which had been installed recently. This equipment, operating on the new single-sideband circuits, is semiautomatic and the vodas (voice-operated device, antisinging) requires little or no attention. The secrecy equipment is of the latest multisplit audio-frequency band-inversion type and enables a total of 137 secrecy combinations to be obtained with automatic change-over every twenty seconds.

Under the direction of A. M. Stevens, the engineering staff of the various associated companies of the International Telephone and Telegraph Corporation guided the members through the installation and explained the various operations.

March 14, 1941, A. T. Cosentino, chairman, presiding.

Buffalo-Niagara

E. E. Spitzer of the transmitting tube department of the RCA Manufacturing Company presented a paper on "New Types and Trends in Transmitting Tubes."

Many of the newer high-frequency tubes were displayed. A cross section of an 827-R showing the construction of the radiator, plate, and internal elements was available. Slides showing the structure of various tubes together with their operating characteristics and ratings were shown.

The RCA 825 inductive-output amplifier tube was described as used in a resonator employing a focusing-magnet structure. Their use in a 1-kilowatt television transmitter at frequencies up to 108 megacycles was outlined.

April 9, 1941, B. E. Atwood, chairman, presiding.

D. G. Fink, managing editor of *Electronics*, presented a paper on "Television Today."

This meeting was held jointly with the Rochester and Emporium Sections at Olean, N. Y.

April 25, 1941, L. C. F. Horle, presiding.

F. A. Lidbury, president of the Oldbury Electro Chemical Company, presented a paper on the "Conn Chromatic Stroboscope as an Audio-Frequency Meter." This device measures frequencies between 32 and 4000 cycles by a rider adjustment of a precision fork which drives, through a chain of gears, 12 stroboscopic disks each corresponding to a semitone of the musical octave and each carrying seven concentric spoked circles corresponding to seven octaves. The frequency to be measured is applied to a flashing lamp and the rider adjusted until the corresponding toothed circle apparently comes to rest.

Although the instrument was developed primarily for musical use, it is proving itself a most accurate and convenient method for the precise measurement of audio frequencies. Various demonstrations were given involving its use as a direct precision frequency meter. Its range may be

extended by using a frequency divider having ratios of $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{8}$, and $\frac{1}{16}$. Its use in conjunction with a crystal oscillator and multivibrators for the precise determination of beat frequencies, permitting crystal precision to be extended to interharmonic frequencies in the radio range, was illustrated by a measurement of the frequency of a local broadcast transmission. Other demonstrations included a visual observation of the deviation in frequency from normal of a 60-cycle line and the measurement of the "wow" of a phonograph turntable.

This was the annual meeting and Ernest Roy of WBEN, Inc., was voted chairman; Frederick Scheer, Colonial Radio Corporation, was elected vice chairman; and Leroy Fiedler, Buffalo Broadcasting Corporation, was re-elected secretary-treasurer.

May 14, 1941, Ernest Roy, chairman, presiding.

Chicago

"Program Aspects in Television Broadcasting" and "Technical Features of Television Transmission and Reception" were presented by W. C. Eddy, director of television, and A. H. Brolly, chief engineer of television development, respectively, of Balaban and Katz (theaters).

Mr. Eddy presented first a brief discussion of the recommendations of the National Television Systems Committee which were submitted to the Federal Communications Commission in an effort to obtain the commercial licensing of television transmitters. These standards were reviewed.

The progress of television during the past few years was outlined and it was pointed out that about 30 station licenses have been granted.

Problems encountered in television programing and their solutions were then considered. The use of miniature settings to provide atmosphere was described.

The organization of a production department for the staging of television shows was then outlined.

Mr. Brolly described the equipment required for a television pickup and broadcast. He traced the circuits from the camera to the antenna. The general requirements for all apparatus were shown and an analysis made of the signals. Mobile equipment and the rebroadcasting of television signals were then considered.

The two authors, assisted by a number of engineers, demonstrated the apparatus used for general pickups. A television camera, lights, amplifiers, and two receivers were used in the demonstration.

March 28, 1941, R. A. Kay, secretary-treasurer, presiding.

In the preliminary session, Charles Hadley, assistant manager of Northwest Airlines, Inc., discussed "Airway Communications."

He outlined briefly the various activities involved in the air-transport industry and showed particularly the responsibility of radio communications. The procedure and the various types of work involved in these communication services were outlined.

Stein

J. D. R. FREED

Joseph David Roth Freed, president of the Freed Radio Corporation, died on April 19, 1941.

Mr. Freed was born in New York City in 1897. He was educated in the New York City schools and received a B.S. degree in 1917 from the College of the City of New York.

Immediately after graduation and until the end of 1918, he served in the Bureau of Steam Engineering of the United States Navy Department in Washington, D. C. For the next three years, he was assistant chief engineer of the Wireless Improvement Company, having charge of the engineering and production of apparatus for the United States Government.

In 1921, he organized the Radio Manufacturing Company which, about a year later, was reorganized as the Freed-Eisemann Radio Corporation. He was president and chief engineer of that organization.

In 1931, Mr. Freed became an executive of Warner Brothers Pictures, devoting himself to its subsidiary, the Brunswick Radio Corporation. In 1938, he joined the Muzak Corporation as vice president and general manager. In 1940, he established the Freed Radio Corporation, with which he was associated at the time of his death.

Mr. Freed joined the Institute as a Junior in 1915, transferring to Member in 1923, and to Fellow in 1928.

Qualifications for air lines radio operators were first discussed and those of the maintenance employees were then considered. Emphasis in maintenance is placed on speed and reliability.

The various types of equipment used both in planes and ground stations were then described. Apparatus used in radio aids to navigation were included.

The activities of the Civil Aeronautics Authority were outlined and their services to navigation shown. Their procedures and report requirements were discussed. The teletype systems used for communications and weather reporting were described.

Airways communication personnel was then considered. Training in meterology and dispatching leads to advancement in responsibility. The average pay scale for such workers and the types of individuals found most suited for this kind of work were outlined.

At the regular session, D. E. Noble, research engineer for the Galvin Manufacturing Company, presented a paper on "Application of Frequency Modulation to Broadcasting and Emergency Communication."

The early developments in frequency modulation were first considered. The theory of this method of transmission was then outlined. Equations representing the frequencies appearing in the frequency-modulated signal were presented. Both the transmitter and receiver were considered and the performance of the various major portions was described. Comparisons were made between frequency- and amplitude-modulation systems.

The equipment used, geographical locations, and graphical analyses of some of the work done by the author with police departments of Connecticut and some of the southern states were then described. Particular emphasis was placed upon the radiator used as to type, location, and radiation pattern.

The practical superiority of frequency modulation was shown in a number of cases. The compact nature and design of frequency-modulation equipment for police service was indicated.

April 11, 1941, G. I. Martin, chairman, presiding.

Cincinnati

Andrew Alford of the International Telephone Development Company, Inc., presented a paper on "Ultra-High-Frequency Antennas and Lines."

The antennas covered in this paper were developed in connection with the Civil Aeronautics Authority for the instrument landing of aircraft. They were mainly of the miniature type, their dimensions being smaller than a half wavelength.

It was shown that with power and frequency constant, greatest response in any desired direction is obtained when the total doublet length is 1.28 wavelengths long. It was observed that little change in response occurred when dropping from 0.5 to 0.1 wavelength provided the higher currents did not increase the losses in the antenna substantially. If very short antennas are to be used, therefore, low conductor resistance is essential.

The ordinary loop provides little radiation in a horizontal plane. By combining loop elements, a circular horizontal pattern of radiation can be obtained with a vertical pattern in the form of a figure eight.

Crossed half-wave dipoles produce a square or approximately rectangular pattern depending on the angle between the dipoles. The vertical pattern is an approximate ellipse having its major axis perpendicular to the plane of the dipoles. This produces intense high-angle radiation and is useful as an aviation marker.

Both vertical and horizontal directivity are obtained with a vertical combination of loops. By adjusting current ratios in the loops, minor lobes in the radiation pattern may be varied. These minor lobes are effected substantially by the current in the top and bottom loops and disappear when these currents are made small.

A comparison was made of the relative merits of stacks of crossed dipoles, stacks of loops, and the half-wave vertical dipole on the basis of the amount of power required to produce a given response. It was pointed out that if a large number of elements are used, the character of the individual element becomes less important as far as power gain is concerned.

April 15, 1941, George Haller, vice chairman, presiding.

J. D. Reid of the Crosley Corporation presented a paper on "Problems Encountered in Frequency-Modulation Receiver Design."

The various stages in a frequency-modulation receiver were listed and their required characteristics pointed out.

The intermediate frequency should be between 13 and 14 megacycles, with a value of 13.7 as optimum. This gives the proper amount of selectivity and eliminates most interference. The 6SK7 is preferred to the 1852 as it gives a slightly higher ratio of mutual conductance to grid-to-plate capacitance.

The oscillator frequency is made higher than the signal frequency which gives a more favorable ratio of changes in capacitance to humidity.

For a frequency swing of 150 kilocycles, the response band for the amplifier is recommended as being 200 kilocycles.

A horizontal dipole antenna is most desirable since it gives less response to ignition noises. The radio-frequency amplifier is designed to give a band pass approximately 10 megacycles wide.

The converter uses an 1852. This tube gives less noise, greater selectivity, greater sensitivity, and more simple design than is obtained with other tubes. The oscillator is a 6SA7. A high-capacitance tuning circuit reduces the effect of the tube warm-up and other temperature changes.

A number of discriminator circuits were described. The use of double coupled circuits results in unsatisfactory operation at the higher frequencies. A method of combining series and parallel tuned circuits to obtain the desired symmetrical response curve produces a discriminator which operates satisfactorily up to at least 100 megacycles. It has the advantage of providing rapid decrease in response beyond the useful part of its operating curve. This reduces adjacent-channel response.

Limiting in the plate circuit was recommended as being more effective than in the grid circuit.

It was pointed out that because of the frequency allocation of frequency-modulation stations, adjacent-channel interference was much more of a problem than is the case with amplitude-modulation stations.

May 13, 1941, J. M. McDonald, chairman, presiding.

Cleveland

"Electronics in Medical Research" was the subject of a paper by H. E. Webber, physicist of the Brush Foundation and Western Reserve University, Department of Medicine.

The application of electronics to biological and physiological study was divided into three parts: the use of amplifiers and recording meters for studying self-generated currents of living tissues, the application of externally generated currents to living tissue to produce various effects, and the use of such instruments as diathermy and high-frequency cautery.

An analogy was drawn between a nerve cell, sometimes several feet in length, and a relay, in that a small stimulus received at one end of the cell is amplified and transformed to the other end of the cell from which it may be transferred to another cell. Nerve currents travel at the rate of from 1 to 90 meters per second and are accompanied by potentials varying between 1 microvolt and 1 or 2 millivolts.

Muscles may be likened to electric motors. They respond to nerve currents but, in contracting, generate a larger current than was received from the nerve. The contraction, relaxation, and possibly the valve action of the heart produce a continuous cycle of electrical phenomena that is conducted throughout the body and permits the diagnosis of heart ailments by such instruments as the electrocardiograph. A new form of this instrument which actuates a pen through the medium of a piezoelectric crystal was demonstrated.

Electroencephalograms which provide records of the minute currents picked up by electrodes placed on the scalp, were discussed. One possible source of these currents is that nerve cells acquire a charge as a result of oxidation from the circulation of the blood and a large number of them discharge simultaneously, like small condensers. The wave form is roughly sinusoidal and has an average frequency of about 10 cycles per second for adults. The voltages average about 8 microvolts but vary in the individual, depending upon age, physiological and mental conditions, and upon the environmental stimuli. The limits of variation appear to be between 1 and 50 microvolts and between 1 and 100 cycles per second. The variation of the characteristic frequency of individuals has been correlated with a number of different physical and mental abnormalities.

The amplifiers used have a flat response-frequency characteristic between 1 and 100 cycles per second. Their outputs are impressed on recording instruments containing 4 Duddell galvanometers.

Short-wave diathermy and cautery were then described and the paper was concluded with a demonstration of the "radio knife."

April 25, 1940, R. L. Kline, chairman, presiding.

"Frequency-Modulation Work Since 1936" was the subject of a paper by E. H. Fritschel, radio and television engineer of the General Electric Company.

Amplitude and frequency modulation were defined and compared. The advantages of frequency modulation in providing a large signal-to-noise ratio, greater dynamic range, and a high over-all transmitter efficiency were described. Both mathematical and physical concepts in the production of frequency-modulated waves were presented.

The results of tests of amplitude and frequency modulation on the effective service areas, harmonic distortion, heterodyne disturbance, signal-to-noise ratios, dynamic range, and propagation properties were shown.

Following the paper, E. L. Gove and R. A. Fox demonstrated many of the effects which were discussed.

Two frequency-modulated-wave transmitters operating at 40 megacycles were placed about 25 feet apart. They radiated different programs. The field strength of one transmitter was varied and the absence of interference and the ability of the stronger signal to take control of the receiver were demonstrated.

An amplitude-modulated-wave receiver was adjusted to receive from W8XNT and one of the frequency-modulation transmitters was adjusted to provide an equal field strength at one of the frequency-modulation receivers. An interfering source generated by a spark discharge was located midway between the receivers. The program from the amplitude-modulation receiver was completely obscured while that of the frequency-modulation system continued without noticeable interference.

May 23, 1940, R. L. Kline, chairman, presiding.

The section was the guest of the laboratories of the Brush Development Company, where a description was given of instruments involving the use of piezoelectric crystals by A. W. L. Williams, president of the Brush Development Company.

The instruments described included a microphone, recording devices of the instantaneous type, ultrasonic instruments, hearing aids, surface-measuring devices, and numerous other laboratory test and design equipment.

September 26, 1940, R. L. Kline, chairman, presiding.

"The Measurement of Noise and Vibration" was the subject of a paper by H. H. Scott of the General Radio Company.

Noise was classified into two types: pitched and unpitched, depending upon whether the noise source is harmonic or shock-excited. The characteristics required of an instrument for measuring noise were then discussed.

Heterodyne- and degenerative-type instruments were described, the latter employing a frequency meter containing a negative-feedback amplifier having variable frequency and amplitude characteristics. This type is considered superior in measuring noise having a slight frequency shift. Numerous applications were described and examples were cited in which unsuspected sources of noise and troublesome vibration were detected. Some of these cases involved measurements at frequencies as low as 2 cycles per second with

displacements ranging between 15 microinches and 2.5 feet.

October 24, 1940, R. L. Kline, chairman, presiding.

W. H. Thoma, an instructor of Aircraft Service, Inc., discussed "Radio Avigation and Airway Aids." This included such aids as sectional maps, radio range beams, weather reports, terrain-clearance indicators, and blind landing systems.

The arrangement and establishment of radio beams were described and the methods used by pilots in finding their way through the intricate network of beams that now interlace the continent were discussed. Direction finders and the radio compass are used in ascertaining a position when, for any reason, this information is not otherwise available. The use of marker beacons and instruments such as the flight-ray indicator were described.

The paper was completed with an imaginary flight requiring the use of various avigation aids from the moment of take-off to the completion of a blind landing with an intervening loss of course charged to bad weather.

November 28, 1940, R. K. Kline, chairman, presiding.

"Meters Used in Radio Communication" was the subject of a paper by J. S. Christie of the Christie Laboratories, Inc.

In an historical outline, it was pointed out that the earliest instruments were water clocks used by the Egyptians. Hog bristles were used as springs in the early days and resulted in the term "hair spring." Hale used the first springs of the present-day types and Hook made scientific studies and evolved the first laws of springs.

Dr. Weston is credited with many developments that have led to the present-day electrical instruments. At the insistence of Edison, the first useful alternating-current instrument was produced in 1907. The early instrument had no provision for zero adjustment.

Manganin, which has a low temperature coefficient, was developed by Weston. The moving coils of the early electrical instruments were heavy and bulky since small wire was not available. Even at the present time, sensitive instruments exert a pressure between the pivot and the bearing in the neighborhood of 2000 pounds per square inch. This construction is required to reduce friction which changes with the deflection.

Ammeters have a high voltage sensitivity, while voltmeters have a high current sensitivity. The sensitivity is limited by the weight and bulk of the moving parts and by the available magnetic flux. Highest sensitivity is obtained by a combination of pivot and suspension types of moving coils.

Thermal instruments in their early design had considerable errors. The error resulting from frequency increases as the current-carrying capacity is made greater. Tubular types of heaters in later high-frequency thermocouples have less than .6 per cent error at frequencies up to 150 megacycles and correction curves are not normally supplied.

March 27, 1941, C. E. Smith, chairman, presiding.

H. A. Erf of the Erf Acoustical Company presented a paper on "Broadcast Studio Acoustics." A brief historical sketch of the study of acoustics beginning in 1432 was first presented. The work of Reed and Sabin was described and the fundamental theories set down by the latter have been improved upon very little.

Many factors are considered in the sound-treating of studios and include location, sound disturbances, number of studios, separation of studios, ventilation, and equipment.

The use of plaster models of auditoriums in the study of their acoustics was described. Flutter echoes were defined and methods of treating opposite walls to eliminate reflections were discussed. Nonuniform absorption is used to provide a proper ratio for the absorption of sounds of different frequencies.

Illustrations of typical plans for modern studios were shown and included methods of floating the structures.

April 24, 1941, C. E. Smith, chairman, presiding.

Connecticut Valley

"An Antenna Review" was presented by E. L. Sanders, development engineer of WTIC.

The theory of simple antennas was first presented. It was then pointed out that if space limitations make it necessary, an antenna may be shortened if it is loaded by a capacitance at the top or an inductance at the center. This results in a higher antenna current than would be obtained with a full half-wave structure, but if the resistive loss in the antenna is kept reasonably small, the field strength will be approximately equal to that of the half-wave antenna. Some experiments in so loading a T antenna formerly used at WTIC were described.

This antenna had too much high-angle radiation and was replaced by a 190-degree vertical structure. Two additional towers are provided to control the directivity pattern of radiation to protect a station in Dallas, Texas. By coupling a pickup coil to the antenna and the towers, rectifying the energy and operating a direct-current meter in the station through a line, a continuous check on the performance of the system is provided.

The design factors for multielement directional arrays were then shown. A graphical method of developing the field pattern of such an array by adding the effects of each element at any given point was described.

A number of high-frequency antennas used in making measurements on transmissions to Boston were then described.

The paper was closed with a description of the frequency-modulation antenna in use at the present time. It is a single-bay vertical coaxial structure.

April 10, 1941, K. A. McLeod, chairman, presiding.

Dallas-Fort Worth

The "Acoustical Side of Loud Speakers" was the subject of a paper by B. C. Hill, Jr.

The subject was introduced by reference to some of the fundamental acoustical formulas and by comparing acoustical resistance and impedance to their electrical equivalents. Consideration was given to the "accession to inertia" of the plug of air which is moved by the diaphragm action.

The characteristics of various types of reproducers were described and the advantages and disadvantages of the spherical and piston types of acoustical radiators were noted. Analogous electrical circuits of acoustical filters were treated as were the different types of horns and cabinet mountings and the various shapes of diaphragms.

The features of conical and exponential horns were compared. The advantage of the exponential horn in cutoff frequency where high-fidelity reproduction is of prime importance was stressed.

If two or more reproducing units are used to cover a wide frequency range, electrical networks separate the currents to the two units. At the cross-over point, some overlap should be provided so that each unit reproduces some of the output near the cross-over frequency. These networks were described.

May 15, 1941, T. I. Kimzey, vice chairman, presiding.

Detroit

"Magnetic Materials" was the subject of a paper by V. E. Legg of the Bell Telephone Laboratories.

The development of magnetic materials during the past few years was described. It was shown how the various "figures of merit" of iron have been increased.

A demonstration was given of a sample of high-permeability iron which loses its permeability when heated, but regains it again after cooling.

February 21, 1941, M. Cottrell, chairman, presiding.

L. N. Holland of the electrical engineering department of the University of Michigan, presented a paper on "Frequency Modulation."

In the first part of his paper, Professor Holland outlined the basic principles of frequency modulation. He made a mathematical comparison of a frequency- and an amplitude-modulated wave. An analysis was given of the spectrum of a frequency-modulated wave and the existence of side frequencies was demonstrated by tuning a sharply tuned amplitude-modulation receiver across the spectrum of a frequency-modulated wave. The distribution of energy in the sidebands and carrier of a frequency-modulated signal was shown.

The circuits of various commercial frequency-modulated-wave transmitters were described and their methods of operation outlined.

The reception of frequency-modulated

waves and their conversion into audible outputs were then covered. The paper was concluded with a listing of the advantages of frequency over amplitude modulation and a discussion of the suppression of noise in a frequency-modulation system

March 21, 1941, M. Cottrell, chairman, presiding.

J. A. Coleman of the RCA Manufacturing Company (Detroit) presented a paper on "Fantasound Systems."

The Fantasound System, which is used in the reproduction of the picture "Fantasia," consists of three complete sound channels. One channel reproduces the sound from the center of the picture and the other two channels reproduce the sound from the two sides of the picture.

Four sound tracks are recorded on a separate film. The extra track records three audio-frequency tones which are used to control the three sound channels. They are separated by filters and their variations in intensity provide the control.

The system installed at the Wilson Theater in Detroit has a total power output of about 300 watts, and a volume range of 65 decibels. A 25-decibel range is recorded on the film and the expansion is effected by the control track.

After the paper, the meeting adjourned to the theater where the last half of "Fantasia" was witnessed. After the performance, the theater equipment, both on stage and in the projection booth, was available for inspection.

April 18, 1941, R. J. Schaefer, vice chairman, presiding.

Emporium

Two papers were presented by members of the Hygrade Sylvania Corporation staff. The first was on "Low-Expansion Alloys for Glass-to-Metal Seals" by W. R. Kingston, metallurgist. The second was on "Safety Engineering" and was by J. J. Lawler, safety engineer.

Mr. Kingston discussed some of the history of glass-to-metal seals. Tungsten and platinum were used until the development of dumet wire which has a nickel-iron core covered with copper which is coated with borax. The most recent developments have been in alloys which match the expansion characteristics of the glass. A chrome-iron alloy is used in the pins in the lock-in line of tubes.

A description was given of some of the work necessary to develop an alloy suitable for this purpose, the various kinds of glass available, the effects of other elements in the alloy, and the desirability of the right oxide to be formed on the surface. Not only must the correct expansion be obtained, but also the differences in heating and cooling of the metal and glass must be considered. The cost and ease of manufacture are important considerations.

Mr. Lawler in his discussion of safety engineering pointed out that the two important things for safety are environment and the human factor. The environment can be controlled to a considerable degree and the safety engineer is concerned mostly with the human-error problems. It is this factor which provides the greatest difficulties.

The position of the safety engineer is between that of the engineer and the workers. As in all other branches of engineering, a factor of safety must always be allowed. As most accidents result from carelessness, the job of the safety engineer is a very difficult one.

April 3, 1941, R. K. Gessford, chairman, presiding.

"Television Today" was presented by D. G. Fink, managing editor of *Electronics*, at a meeting held jointly with the Buffalo and Rochester Sections at Olean, N. Y.

The subject was viewed from three angles: what has been done and can be done, the National Television Systems Committee and its work, and the resulting effect on government and industry.

In treating the first phase of the subject, the advantages and disadvantages and the many engineering problems facing television were outlined. By a series of slides, a complete sequence of television from the televised subject, through the studios, the camera, the lighting, and the control booth and thence to the receiver, was presented. Unusual broadcasts illustrating the wide range of usefulness of these transmissions and the equipment which made them possible were illustrated.

The second part of the talk was concerned with the National Television Systems Committee and its work. The changes made in arriving at the present television standards and their effect on the industry were outlined.

The demonstrations made for the Federal Communications Commission to show the progress of the industry as well as its range of service to the public were then described. The importance of television in national defense was emphasized. In conclusion, the possibilities of television for this year were considered.

April 25, 1941, L. C. F. Horle, presiding.

"The Influence of Contact Potential on Vacuum Tubes" was the subject of a paper by G. D. O'Neill, engineer for the Hygrade Sylvania Corporation.

Contact potential may cause so many effects on tube characteristics that a knowledge of the theory underlying it is necessary for proper tube design. Pure contact potential is difficult to measure and may be masked by many other factors such as cleaning, aging, gas, leakage, and initial electron velocity. The term is usually applied to all these effects as they are indicated by a single measurement, usually of the grid-current reversal point.

The effects of contact potential on the characteristics of a simple diode were first considered and the equations for the current and voltage relations were discussed. The effects in a triode were then considered. In treating more complex multielement tubes, they are broken down into the triode form and the pertinent equations applied.

In conclusion, figures from life-test data for two different types of tubes were presented and illustrated the changes in contact potential with age and the resulting effects on the tube characteristics.

May 22, 1941, R. K. Gessford, chairman, presiding.

Indianapolis

Two papers were presented by research engineers of the Farnsworth Television and Radio Corporation. The first was by J. D. Schantz and considered "Modern Television Control-Room Equipment." The second was on a "Portable Single-Channel Radio Manufacturers Association Signal-Generator for Television" by W. H. Nelson.

Mr. Schantz presented a brief account of typical cameras using Farnsworth dissector tubes. This was followed by a description of the equipment which comprises the master timing unit, synchronizing and blanking-pulse generators, and camera control circuits. Both the mechanical and electrical features were considered.

A novel control desk or console incorporates the operating controls and monitors. The camera focusing, background, and contrast controls are handled remotely by the operator at the desk. Two monitor and two oscilloscope tubes are mounted in the console. Complete power supplies and amplifiers are contained in the console as are other control circuits. These are so arranged as to permit easy access to all components for adjustment and servicing.

Mr. Nelson described a portable, complete television channel, comprising sight and sound signals conforming to the Radio Manufacturers Association standards. This is an important adjunct to television test equipment. It is intended to work with the generators and other equipment described by Mr. Schantz.

The equipment is flexible in operation and is compactly housed in a small cabinet. It includes video, synchronizing, and pedestal amplifiers, clipper, mixers, and two radio-frequency channels. The nature of the signal may be varied over wide ranges by means of a combination of crystals.

The basic 61.25- and 65.75-megacycle picture and sound channels are provided and up to five receivers may be operated at one time without interaction. The output may be varied between 25 microvolts and 6 volts into a 72-ohm line.

April 18, 1941, A. N. Curtiss, chairman, presiding.

This was the annual student meeting and papers were presented by four students of the School of Electrical Engineering of Purdue University.

"A Report On Experiments With Superregeneration" was presented by G. F. Montgomery. A large number of oscillograms taken of the operation of a superregenerative receiver were used to illustrate the theoretical discussion of the subject. A receiver was also used to demonstrate the improvement in signal-to-noise ratio through the use of coupled tuned circuits. Considerable improvement was also predicted by employing a tuned radio-frequency stage ahead of the detector. The noise under discussion was that generated in the detector circuit.

A "Demonstration of a Frequency-Modulation Monitoring System" was given by W. L. Mraz. The system is similar to that described by Pieracci in the August,

1940, PROCEEDINGS. The mathematical series used to define the components of the modulation was developed and was illustrated on a cathode-ray oscilloscope. The demonstration showed the feasibility of checking various important transmission characteristics.

"A New System of Remote Control for a Radio Receiver" was discussed by K. E. Yost. It employs a radio transmitter modulated at various audio frequencies. By means of a filter system and trigger tubes, these audio frequencies operate selector relays. By interlocking and release methods, a reduced number of relays and tubes can be used. The relays are simple and readily serviced. A 6-station selector combined with a volume control and off-on switch was described.

J. A. Green, presented a "Description of a 'Warble-Tone' Loud-Speaker Testing Equipment." The warble note overcomes the effects of standing waves at the point at which the pickup microphone is located. Various components of the equipment were described, and the complete test setup was inspected.

An inspection trip, guided by faculty members and students, was made through the new studios of WBAA and the new Music Hall where details of the stage operation, lighting arrangements and controls, projection booth, and public-address system were explained.

May 16, 1941, A. N. Curtiss, chairman, presiding.

Kansas City

This was the first meeting of the Kansas City Section since it was recently established. In the election of officers, Harner Selvidge, professor of electrical engineering at Kansas State College, was named chairman; H. K. Morgan, superintendent of communications at Transcontinental Western Air, was designated vice chairman; and G. L. Taylor, president of Midland Television, Inc., was elected secretary-treasurer.

A paper on "Ultra-High-Frequency Propagation" was presented by Harner Selvidge.

April 15, 1941, Harner Selvidge, chairman, presiding.

Los Angeles

"Recent Developments in Frequency-Modulation Receiver Design" was the subject of a paper by P. G. Caldwell, application engineer of the General Electric Company.

It was pointed out that with an intermediate frequency of 4.3 megacycles, it was difficult to obtain sufficient gain with a conventional superheterodyne circuit. In the receiver design being discussed, a double-conversion superheterodyne is employed which utilizes only one oscillator instead of two. This provides the necessary gain and at the same time objectionable heterodynes are eliminated. Another advantage is that the oscillator is operated at a lower frequency than in a conventional superheterodyne and this minimizes oscillator frequency drift.

The limiter problem was discussed in general, and particular reference was made to the use of a cascade circuit.

The second paper of the evening was on "Constant-Groove-Speed Recording" by Richard Leitner, engineer of Frank Rieber, Inc.

The constant groove speed is accomplished by the use of a drive wheel engaging the turntable directly below the needle point. It makes possible a recording cost of approximately 10 cents per hour on a thin 12-inch plastic record.

The embossing head is carried across the disk by means of a lead-screw mechanism. A recording speed of 4 inches per second allows satisfactory operation between 200 and 4000 cycles. No noticeable speed variation was observed at voice frequencies.

A permanent cutting needle which does not need resharpening, and which embosses a groove without cutting a chip, is employed. Immediate playback is provided and the records may be used an indefinite number of times without noticeable deterioration.

The entire presentation of the paper was recorded and played back as a demonstration of the effectiveness of the recording. Through the use of compression and peak-limiting circuits, the playback level was practically the same throughout the recording, although the speaker's distance from the microphone varied between one and fifteen feet during the presentation of the paper.

March 18, 1941, W. W. Lindsay, Jr., chairman, presiding.

Montreal

J. V. Argyle, manager of the Inland Communications Division of the Canadian Marconi Company, Ltd., presented a paper on "Frequency Modulation."

The paper was opened with a discussion and comparison of the services rendered by amplitude- and frequency-modulation systems, providing at the same time an outline of the development of frequency modulation. A description was given of work which has been done in applying frequency-modulation systems to point-to-point services and police communications. A demonstration of the former service was made by the Canadian Marconi Company.

March 26, 1941, M. L. Patience, chairman, publicity committee, presiding.

Philadelphia

"Some Problems of Disk Recording" was the subject of a paper by S. J. Begun of the Brush Development Company.

In considering home recording, the optical method was eliminated because of the necessity of processing the record before it can be reproduced. Magnetic and mechanical recordings are both suitable although, at present, only mechanical methods are used. Magnetic recording has the advantage in that the record can easily be erased, making the magnetic sound carrier available for a new recording.

In analyzing mechanical recording, cylinder, tape, and disk records were discussed. The latter was recommended since most commercial records are available in this form and should be reproducible by the home-recording equipment.

The design features of magnetic and piezoelectric recording heads were analyzed. In magnetic heads of the low-price range, rubber or similar material is used as a damping medium. They are not entirely satisfactory since these materials have a nonlinear damping characteristic, as well as a nonlinear stiffness characteristic. Information was then presented on piezoelectric-crystal cutting heads which have been recently developed, including a stabilized temperature-controlled unit.

Record materials were then considered, and while cellulose nitrate has definite shortcomings, it is sufficiently good as not to handicap further the development of home recording.

Emphasis was laid on the desirability of turntables with constant speed and freedom from vibration. A string-driven turntable which has given excellent results was described.

It was pointed out that a recording characteristic similar to that used in commercial pressings is desirable as it permits the playing of commercial records on home-recording equipment. If a more elaborate home-recording instrument is desired, a constant-amplitude characteristic was recommended for all frequencies above 200 cycles and a constant-velocity characteristic below this transition point.

April 3, 1941, C. M. Burrill, chairman, presiding.

"A 5-Band Receiver for Automobile Service" was the subject of a paper presented by F. X. Rettenmeyer of the RCA Manufacturing Company (Camden). This paper was published in the April, 1941, issue of the PROCEEDINGS.

This was the annual meeting and C. C. Chambers of the University of Pennsylvania was elected chairman; J. B. Coleman of the RCA Manufacturing Company was named vice chairman; and R. L. Snyder was re-elected secretary-treasurer.

May 1, 1941, C. C. Chambers, vice chairman, presiding.

Pittsburgh

"Frequency Modulation" was the subject of a paper by G. A. Scott, of the University of Pittsburgh.

Professor Scott explained first the characteristics of a frequency-modulated carrier. This was followed by a presentation of present methods and circuits employed for frequency modulation, emphasizing their relative advantages and limitations. The requirements of the Armstrong system to raise the carrier frequency and the carrier-frequency modulation shift to the desired level were outlined. The essentials for the reception of a frequency-modulated carrier were described and the methods and circuits employed were discussed. In conclusion, a comparison was made of the relative merits of frequency and amplitude modulations on the basis of transmitter power requirements and the quality of the received signals.

April 23, 1941, P. N. Bossart, vice chairman, presiding.

Three papers were presented by students of Carnegie Institute of Technology.

"New Developments in Electronic Musical Instruments" was the title of the paper presented by Jobe Jenkins. The second paper was on the "Generation and Use of Ultrasonics" and was by V. G. Shaw. The "History and the Preparation of Quartz Crystals" was the title of the third paper which was given by M. L. Levy.

May 12, 1941, R. E. Stark, chairman, presiding.

Portland

The members of the Portland section were the guests of Oregon State College for an afternoon and evening meeting.

During the afternoon, inspections were made of the new KWIL transmitter and of the directional antenna system at KOAC.

In the late afternoon, a paper on "A Graphical Method for Determining Directional Antenna Characteristics" was presented by E. A. Yunker, associate professor of physics at Oregon State College. A demonstration was included. A. L. Albert, presided.

At the banquet which was presided over by W. H. Huggins, greetings were extended by R. H. Dearborn, dean of the School of Engineering.

The evening session was presided over by F. O. McMillan. "Factors in the Development of the KOAC Antenna Array" were presented by Grant Feikert, chief engineer of KOAC and assistant professor of electrical engineering at Oregon State College. "A Discussion of Reflection Theory" was then presented by A. L. Albert, professor of communication engineering at Oregon State College. A "Demonstration of a Television Signal-Generator" was then presented by F. A. Everest, assistant professor of electrical engineering at Oregon State College.

April 5, 1941.

San Francisco

"Frequency Modulation" was presented by H. J. Scott, professor of electrical engineering at the University of California.

A comprehensive discussion of the characteristics of frequency-modulated waves was given. Comparison with amplitude-modulated waves was made both from the standpoint of the frequency spectrum, showing the difference in the sideband structure, and from the standpoint of the vector diagram showing the composition of the signal and illustrating the phase difference between the two types of modulation. The mechanism of the noise reduction was explained and results of experiments along this line were reported. As an incidental aspect of the subject the difference between phase and frequency modulation was discussed, and the approximately constant band width of the frequency-modulated wave explained.

February 19, 1941, L. J. Black, chairman, presiding.

"Developments in Radio Aids to Navigation" were discussed by P. C. Sandretto, superintendent of communication laboratories of United Airlines.

A review was presented of the history of navigation aids and the indicated present trends. Particular emphasis was placed on the limitations of existing systems and proposed changes were discussed. The results of extensive operation of these services were revealed. Some of the effects and distortion of beams in mountainous regions were given special attention.

March 20, 1941, L. J. Black, chairman, presiding.

As a second paper in a series on frequency modulation, "Reception of Frequency-Modulation Signals" was presented by J. M. Pettit of the department of electrical engineering of the University of California.

A comprehensive treatment was given of frequency-modulation receivers. The characteristics of the limiter and discriminator stages were discussed in particular detail. A demonstration of a portable frequency-modulation transmitter and receiver was presented. The dynamic range and high-frequency fidelity were illustrated by transmitting various sounds such as hammer blows, sawing, water being poured, and the playing of a piano. The ability of a frequency-modulation signal to override interference was strikingly demonstrated.

April 2, 1941, L. J. Black, chairman, presiding.

"Fantasound, the Sound System Behind Fantasia" was presented by Allan Hyne of the Photophone Division of the RCA Manufacturing Company.

The presentation of the paper was preceded by an inspection of the equipment and a demonstration at the Geary theater at which "Fantasia" is being shown. The control room was visited and the special equipment installed for the show was examined.

Of particular interest were the quadruple sound tracks and the multiple head for separating the channels. The picture and sound are on separate films which are run synchronously.

The sound film has four push-pull tracks representing three sound tracks and a pilot signal. The latter records three control frequencies which are separated by filters and determine the volume of the three sound channels.

The output of the three sound channels are fed to units on the stage behind the screen and to a number of small speakers distributed throughout the theater to give the effect of sound originating from the sides and the back.

The demonstration consisted of a showing of the last reel of "Fantasia." About 65 watts of acoustic power were produced at the peaks. The dynamic range, fidelity, and directional effects were well illustrated.

At the meeting afterward the technical details of the system were explained.

President Terman was present at this meeting and reviewed recent activities of the Institute. He discussed the developments in the field of radio and communications in the East.

April 30, 1941.

Two papers were given at this meeting by graduate students in electrical engineering. The first paper on "Generation of Subharmonics" was by J. S. Prichard of the University of California.

A method of generating subharmonics, which is quite different from the usual multivibrator circuit, was described. The output of a modulator, filter, and amplifier is partially fed back to the input through a limiter and harmonic generator. The frequencies are adjusted so that the difference between the multiple of the output fed back to the input and the input is the desired subharmonic. High stability and excellent output wave form are obtained. In practice, the device contains 3 tubes per stage and is easily made to give a frequency division of 20.

The second paper was on the "Measurement of Complex Impedance at 3000 Megacycles" and was by Victor Carson of Stanford University.

The method makes use of the impedance-converting properties of transmission lines, in this case coaxial cables. Any impedance at the end of a line can be made to give an input impedance equal to the characteristic impedance of the line by adjusting the line length to the proper value and putting a parallel resistance across the input to the line by means of a section of a short-circuited line adjustable in length. The condition of input impedance equal to characteristic impedance is tested by measuring the current distribution in the feeding line. When this current is constant the line is properly terminated. Values of terminal impedance are read directly from a circle-diagram chart from the length of the line and the short-circuiting stub line.

The student prize was awarded to Mr. Carson.

May 14, 1941, L. J. Black, chairman, presiding.

Toronto

"Intermediate-Frequency Transformer Design and Construction" was the subject of a paper by F. J. Frater of the F. W. Sickles Company.

The intermediate frequencies used today cover a wide range. In household broadcast receivers they vary between 456 and 470 kilocycles with major standardization at 455 kilocycles. This standardized figure is not always usable because of interference problems. For amateur receivers, when operating on high-frequency bands, intermediate frequencies of 1600 and 5000 kilocycles are used. Automobile receivers commonly use a frequency of 262 kilocycles. In frequency-modulation receivers, the intermediate frequencies vary between 2 and 4.3 megacycles.

The information necessary to design an intermediate-frequency transformer was then outlined and several formulas presented for obtaining required data. Single-, double-, and triple-tuned types of transformers were described and their selectivity characteristics compared.

The construction of transformers was next covered. The simplest and cheapest type of winding is the single pie. The smallest single wire size used is No. 38 and with it, it is possible to obtain a Q of 60 in a 1-inch square aluminium shield. The next

best conductor is 2 strands of No. 41 with which a Q of 75 can be obtained.

Other important features in construction were described and included the type and size of shield, the placement of coils within shields, and the design of trimmer capacitors. Graphs were shown indicating the variation of coupling with coil space, the effect of coupling on gain, overcoupling and regeneration, and selectivity under varying operating conditions.

April 7, 1941. R. H. Klingelhoeffer, vice chairman, presiding.

R. F. Field, engineer for the General Radio Company, presented a paper on "Impedance Measurements at Frequencies from 1 to 100 Megacycles."

It was stated that there were three fundamental standards, those of resistance, capacitance, and inductance. None of these are obtained in a pure state, the important correction factor in all measurements being related to the residual impedance present in the standard itself and the residual impedance of the leads used to connect the standard into the circuit.

Inductance standards are unsuited for high-frequency measurements, except in isolated cases, because of the high impedances which result. Resistance and capacitance standards were then discussed and formulas and characteristics were given for them. It was pointed out that resistance standards can be built giving an error of only 2.5 per cent at 100 megacycles. This is better than for capacitance standards where the lowest error obtainable at present is of the order of 10 per cent with 100 micromicrofarads at 60 megacycles.

The relative merits of resistance and capacitance standards were considered. Capacitors have the advantage of more definite characteristics and less variation between variable and fixed units. Variable resistors were considered unreliable as standards.

This was the annual meeting and R. H. Klingelhoeffer of the International Resistance Company, Ltd., was elected chairman; T. S. Farley of T. S. Farley, Ltd., was named vice chairman; and L. C. Simmonds was re-elected secretary-treasurer.

May 5, 1941, R. H. Klingelhoeffer, vice chairman, presiding.

"Directional Antennas for Broadcast Stations" was the subject of a paper by B. de F. Bayly, consulting engineer and professor of electrical engineering at the University of Toronto.

The reasons for directional antennas were first considered. In Canada, there are many low-powered stations located outside the limit of cities which they desire to serve. By using directional antennas, most of the radiation can be concentrated over the area containing the largest population. In other cases, directional antennas are used to prevent interference with other stations.

Although at the present time there is only one Canadian broadcast station using a directional antenna, a number are under consideration or construction. As a result of the adoption of the Havana agreement, at least 5 stations are operating temporarily on reduced power because of a lack of directional antennas.

The design of directional antenna systems was then considered and the economic factors were stressed. The effect of the number of towers on the radiation pattern was discussed. The results of varying the phase relations of the current in these towers were outlined and physical and electrical means of controlling the phase relations were considered. The paper was closed with a discussion of the types of radiators found useful in this field.

April 21, 1941, R. H. Klingelhoeffer, vice chairman, presiding.

Washington

"New Types and Trends in Transmitting Tubes" was the subject of a paper by E. E. Spitzer of the research and engineering department of the RCA Manufacturing Company (Harrison).

The development of ultra-high-frequency broadcasting, police radio, television, frequency-modulation, and commercial aircraft services, has resulted in a continual trend toward the use of higher frequencies. The development of transmitting tubes for these purposes was outlined and their gradual improvement to approach the standards of performance obtained at lower frequencies was discussed.

The comparative ease of obtaining high frequencies with an oscillator tube in contrast with the difficulties in developing a satisfactory amplifier tube providing low distortion, low noise level, and good efficiency was discussed. The advantages of the beam tubes over triodes, particularly from the standpoint of low driving power and the elimination of neutralization problems, were outlined. It was pointed out that push-pull construction is particularly effective in reducing screen- and cathode-lead inductances.

The paper was illustrated with data on a number of ultra-high-frequency tubes designed for use as amplifiers.

April 14, 1941, M. H. Biser, chairman, presiding.

A. B. Chamberlain, chief engineer of the Columbia Broadcasting System, presented a paper on "C.B.S. International Broadcast Facilities."

The significance of the present international broadcasting situation, its growth, and present status in both the Eastern and Western hemispheres, were discussed. A description was given of the new transmitting plant located at Brentwood, Long Island. The problems attendant to successful relaying of programs to foreign countries, including facilities for such services as studios, frequency-modulation program relay circuits, and two complete 50-kilowatt transmitting plants were described.

The design features and operating characteristics of the transmitting apparatus were discussed. Thirteen directive antenna arrays and their associated transmission lines were described.

The population and receiver distribution in the South American countries, together with the directional radiation patterns of the antennas, were presented to show the coverage which this system will provide.

May 12, 1941, M. H. Biser, chairman, presiding.

Circuit-Designation Method

Dr. O. H. Caldwell, editor of *Radio and Television Today*, has supplied information concerning a novel system for presenting diagrams of circuit wiring in such fashion that the paths of the various types of current may be easily identified.

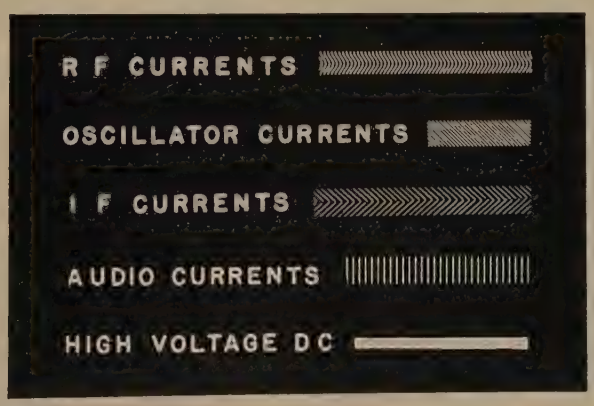


Fig. 1

In Fig. 2, the different crosshatching patterns overlaying the grid and plate circuits of the various stages should be noted. A distinctive pattern is used for each of the different fundamental frequencies found in the receiver. These patterns are graduated in order of the magnitude of the frequencies they represent. That is, the oscillator circuit, which in most cases has the highest frequency currents, is identified with the closest mesh pattern. Next come the radio-frequency circuits with a slightly coarser pattern; then the intermediate-frequency wiring; and finally the audio-frequency circuit with coarsest marking. The alternating-current power circuits are not marked because of the ease with which they are identified.

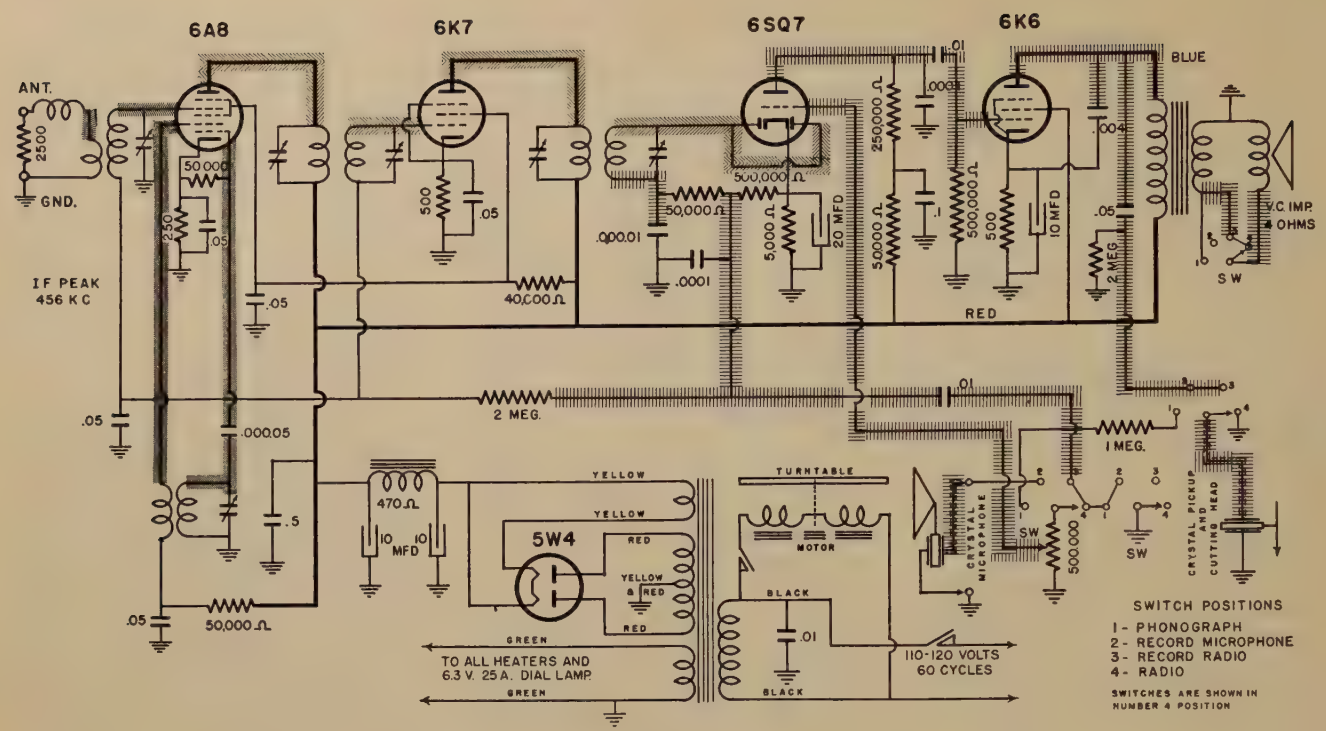


Fig. 2

In Fig. 1 the coding method of designating the individual circuits is summarized.

The claimed features of usefulness of the system are listed (in relation to speedy indication of the following):

1. Where the signal should be and what its frequency should be. This also shows where to place signal-tracing equipment.
2. Parts of the circuit where the signal should not be.
3. Where to measure the signal at each frequency.
4. Where to apply the signal of the correct frequency to get a "dead" set working.
5. Which leads have high direct voltage.
6. Which components are used to couple the signal, and which are used to isolate or block it.
7. The job that each tube is doing.

It is further claimed that this signal-path system should aid in the analysis of complicated circuits, speed up the tracing of the circuits, and expedite the location of the trouble using presently available signal-analyzing and tracing equipment.

In view of the possible interest of this method of circuit designation to engineers, instructors, draftsmen, servicemen, and the standardizing groups in The Institute of Radio Engineers, the preceding material is here included as an editorial note.

Membership

The following indicated admissions and transfers of memberships have been approved by the Admissions Committee. Objections to any of these should reach the Institute office by not later than July 31, 1941.

Transfer to Member

Ayres, R. C., 5423 Chadwick Rd., Kansas City, Kan.
Gerks, I. H., Aircraft Radio Laboratory, Wright Field, Dayton, Ohio.
Hartig, H. E., University of Minnesota, Minneapolis, Minn.
Herbst, P. J., Farnsworth Television & Radio Corp., Fort Wayne, Ind.
Hobbs, M., 4941 N. Wolcott Ave., Chicago, Ill.
Honnell, P. M., 3136 Westminster Ave., Dallas, Texas.
Hunt, F. V., 4 Glenn Rd., Belmont, Mass.
O'Reilly, G. A., 5505 Chadwick Rd., Kansas City, Kan.
Thomsen, P. H., 903 Philadelphia Ave., Silver Spring, Md.

Admission to Member

Bode, H. W., Bell Telephone Laboratories, 463 West St., New York, N. Y.
Boyajian, J. A., 6424 N. Troy St., Chicago, Ill.
Brumbaugh, J. M., 93 La Crosse Ave., Lansdowne, Pa.
Chambers, D. E., 46 Sanders Ave., Scotia, N. Y.
Doll, H. G., 2720 Leeland Ave., Houston, Texas.
Franklin, J. C., TWA, Inc., Kansas City, Mo.
Hoard, G. L., University of Washington, Seattle, Wash.
McMillan, F. O., 2990 Harrison St., Corvallis, Ore.
Phinney, E. D., International Tel. & Tel. Corp., 67 Broad St., New York, N. Y.
Rieber, F., 11916 W. Pico Blvd., Los Angeles, Calif.
Rogan, J. J., 41 Park Row, New York, N. Y.
Starrett, J. S., Box 106, Denville, N. J.
Van Lieshout, L. J. A., 18 Storer Ave., Pelham, N. Y.
Weber, E., Polytechnic Institute of Brooklyn, Brooklyn, N. Y.
Wilcox, J. V., 3947 State Line, Kansas City, Mo.
Williams, R. O., Box 342, Roscommon, Mich.

The following admissions to Associate grade were approved by the Board of Directors.

Albers, J. M., Webster Hall Hotel, Detroit, Mich.
Alford, W. D., Canadian Marconi Co., Mount Royal, Que., Canada
Allen, R. L., University of Western Ontario, London, Ont., Canada
Arne, R. E., 1147 N. Fuller Ave., Los Angeles, Calif.
Baker, G. W., 610 W. 116th St., New York, N. Y.
Booth, A. A., 6792 Upper Lachine Rd., N.D.G., Montreal, Que., Canada
Bothel, K. W., R.R. 5, Sidney, Ohio.

Bresenham, J. J., Jr., 402 N. Winnetka St., Dallas, Tex.
Broman, H. F., 1236 New York Ave., Brooklyn, N. Y.
Burton, R. R., National Youth Administration, 2145 C St., N.W., Washington, D. C.
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Clarkson, L., 4408 Kensington Ave., N.D.G., Montreal, Que., Canada
Cooke, R. W., Canadian Marconi Co., Mount Royal, Que., Canada
Cosby, J. R., Box 349, Blacksburg, Va.
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Davis, R. C., 501 Liberty St., Boonton, N. J.
Deisinger, D. A., 26 Wallace St., Red Bank, N. J.
d'Humy, F. E., Western Union Telegraph Co., 60 Hudson St., New York, N. Y.
Domidion, W. G., Jr., 188 Spring St., Red Bank, N. J.
Druz, W. S., 2915 N. Dawson Ave., Chicago, Ill.
Dubofsky, H., 419 Garden St., Hartford, Conn.
Effertz, C. H., 1815 Berkeley Ave., St. Paul, Minn.
Freeman, H. L., 77th CA (AA), Fort Bragg, N. C.
Goetter, W. F., 1307 Union St., Schenectady, N. Y.
Goodstine, H., 148 Bissell St., Manchester, Conn.
Greene, R. E., 842 N. Tuxedo St., Indianapolis, Ind.
Hartz, F. M., 19345 Teppert Ave., Detroit, Mich.
Hodes, I., 719 Alabama Ave., Brooklyn, N. Y.
Hodgson, D. T., 7467 Outremont Ave., Montreal, Que., Canada
Hokanson, H. P., General Radio Co., 30 State St., Cambridge, Mass.
Kokoskin, W. J., 6347 Marquette St., Montreal, Que., Canada
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Lafferty, R. E., 412 Knox St., Odgensburg, N. Y.
Lamb, J. F., Carnegie Institute of Technology, Pittsburgh, Pa.
La Pierre, V. M., Pan American-Grace Airways, Inc., Lima, Peru
Tenenbaum, F., 565 W. 2nd St., Dayton, Ohio.
Leslie, D. M., Box 2123 Georgia School of Technology, Atlanta, Ga.
Lieb, J. M., 1453 Alabama Ave., Pittsburgh, Pa.
Lloyd, J. E., 1244 Hemlock Lane, Ventura, Calif.
Lookingbill, D. C., 30 W. Chicago Ave., Chicago, Ill.
Lowe, D. M., 1400–29th St., S.E., Washington, D. C.
Mackiernan, D. S., Jr., R.F.D., Stoughton, Mass.
Markus, L. J., 3061 N. Quincy St., Arlington, Va.
McCormack, R. L., 303A Holden Green, Cambridge, Mass.
Millman, J., City College of New York, 139th St. & Amsterdam Ave., New York, N. Y.
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Moody, W. R., 403 W. 205th St., New York, N. Y.
Nelson, R. F. 607 Division St., East Lansing, Mich.
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Shirling, G. K., 1523 E. 59th St., Kansas City, Mo.
Smith, D. S., Mystic, Que., Canada.
Steiger, B. F., 504 Prospect St., Maplewood, N. J.
Teare, B. R., Jr., Carnegie Institute of Technology, Pittsburgh, Pa.
Tejada, L. H., Casilla 675, La Paz, Bolivia.
Torian, R. B., 435 Pine Ave., Long Beach, Calif.
Vladimir, L. O., c/o Howell, Roseville Rd., Westport, Conn.
Vogel, V. H., Collins Radio Co., Cedar Rapids, Iowa
Wallace, R. J., c/o Canadian Marconi Co., Mounta Royal, Que., Canada
Wallman, H., Chapel Hill, N. C.
Watts, C. B., Jr., 200 Mount Pleasant Ave., Newark, N. J.
Wickenkamp, F. W., Route 4, Box 262A, Tucson, Ariz.
Wimpie, S., 701 W. 177th St., New York, N. Y.
Wood, L. M., 1211 Oak Grove Dr., Los Angeles, Calif.
Woodward, M. W., 8238 Belleview, Kansas City, Mo.
Wright, R. R., Box 20, New York University, New York, N. Y.

Books

Geomagnetism, by Syndey Chapman and Julius Bartels

Published by the Oxford University Press, 114 Fifth Avenue, New York, N. Y. 2 volumes. 349 figures. 38 plates, 1007 pages, +41-page index. Price $18.00. $6\times9\frac{1}{4}$ inches.

As the authors point out in their preface, it has been forty years since a really comprehensive treatise on geomagnetism has been published In these four decades the physics of the atom and of radiation were born, so only recently could a consistent physical explanation have been given of the relation between solar activity and geomagnetism. It is also within this same period that radio communication over distances involving sky waves came into being, and finally gave us our first detailed knowledge of the ionsphere, itself initially a magnetician's concept.

Chapman and Bartels have admirably succeeded in presenting the observed facts of geomagnetism, their analysis and physical interpretation. A lucid text, a wealth of skillfully prepared illustrations, and an excellent bibliography make this an invaluable reference book to either those interested in the general subject of geomagnetism, or related subjects such as geophysical prospecting or radio communication. The radio engineer concerned with transmission phenomena will find chapters XI and XII of particular interest, especially as to the predictability of ionospheric disturbances.

GREENLEAF W. PICKARD
Seabrook Beach, N. H.

M.K.S. Units and Dimensions, by G. E. M. Jauncey and A. S. Langsdorf

Published by the Macmillan Company, 60 Fifth Ave., New York, N. Y. 62+viii pages. 5 figures. No index. $5\frac{3}{4}\times8\frac{5}{8}$ inches. Price,$1.00.

The International Electrotechnical Commission (IEC), in 1935, adopted as a world-wide standard, the meter, kilogram, and second as the basic units of length, mass, and time, this action to become effective January, 1940. Since this system of units will appear in the literature, radio engineers should be familiar with the advantages claimed for it. In this connection the little book by Jauncey and Langsdorf entitled "M.K.S. Units and Dimensions" will prove helpful. The authors discuss the properties of the new system of units, methods for changing from one system of units to another, reasons for adopting the ohm as the fourth basic unit, a proposed MKOS system, and the difference between magnetic flux density (B) and magnetic field strength (H). The presentation is clear and informative. A careful reading of this book will disclose the disadvantages as well as the advantages of the M.K.S. system. For example, in discussing the proportionality factors of the cgs system, which appear as integral powers of 10, the authors say "In

the M.K.S. system all of these awkward factors disappear. They do so partly because of the change from centimeters and grams to meters and kilograms, partly because flux density (B) instead of being expressed in maxwells per square centimeter is expressed in webers per square meter, where the weber is 10^8 maxwells. But in addition to this simplification, it is necessary to take the numerical value of the permeability of free space as 10^{-7} instead of unity, and this means not only a clarification of ideas concerning the meaning of permeability but also a clear-cut distinction between flux density (B) and magnetic field strength (H)." These simplifications will undoubtedly do violence to the ideas and conceptions of many engineers. There is a further disadvantage in that this M.K.S. system of the International Electrotechnical Commission makes the electromagnetic equations unsymmetrical.

H. M. Turner
Yale University
New Haven, Conn.

Report on the Progress of Broadcasting in India

Published by the Manager of Publications, Delhi, India. Printed by the Manager, Government of India, Press Simla, India. 230+xiv pages. 20 photographs and 68 graphs and maps. $6\frac{1}{2}\times9\frac{3}{4}$ inches. Price Rs. 3 or 5s.

This is the first formal publication reporting on the activities of All India Radio (formerly the Indian State Broadcasting Service), a Government of India organization responsible for broadcasting in India. Since it is an initial report, the material includes an historical survey of the development of broadcasting in India since its inception in 1927.

The book includes, in addition to the early history, chapters on the technical development plan, the program material broadcast, public relations, engineering design and measurements, administration, licensing regulations, and radio publications. The material that is of particular interest to the radio engineer comprises about one quarter of the book, while the majority of the photographs and figures are of technical interest.

The book is well written and presents a very complete picture of broadcasting progress in India up to March 31, 1939.

H. A. Chinn
Columbia Boradcasting System
New York, N. Y.

Electromagnetic Theory, by Julius Adams Stratton

Published by McGraw-Hill Book Company, Inc., New York, N. Y., and London, England, 1941. 615 pages, 116 figures. $6\frac{1}{4}\times9\frac{1}{4}$ inches. Price $6.00.

Professor Stratton's "Electromagnetic Theory" is an advanced and highly mathematical textbook. Maxwell's equations are postulated at the start, on page 2 to be exact, and the remaining 600 pages are devoted to deductions from these equations and corresponding physical interpretations. About one half of the book is given to conventional topics and the rest to topics which, on account of their engineering importance, have been developed in detail in the last few years. Thus, the first four chapters deal with scalar and vector potentials, stresses and strains, energy relations, electrostatics, and magnetostatics. The fifth chapter contains a modernized treatment of plane waves; the sections on various velocities of wave propagation are both interesting and instructive and for the first time in a textbook both characteristic properties of a wave are treated, the characteristic impedance as well as the phase velocity. Chapters 6 and 7 deal successively with cylindrical and spherical waves. A thorough discussion of radiation patterns of antenna arrays, heretofore found only in strictly engineering textbooks, comprises chapter 8. In the concluding chapter 9, representing over one fifth of the entire book, various boundary-value problems are grouped together. In this chapter the reader will find discussions of reflection and refraction of plane waves, wave propagation in metal tubes and along coaxial lines, free oscillations of a sphere, diffraction of plane waves by a sphere, and a concise summary of wave propagation over a plane earth. Excellent sets of problems follow various chapters.

The author's exclusive use of the rationalized M.K.S. or Giorgi system of units is to be particularly commended. From the points of view of the mathematical and the laboratory engineers alike this system is unquestionably superior to the classical systems of units. This obvious superiority must account for the rapid conquests made by the M.K.S. system in the last few years.

Generally speaking, in his choice of the subject matter the author has kept his eye on engineering applications and the treatment, while highly mathematical in spirit, shows ample evidence of consideration for the needs of the engineer. In this respect the present volume represents a distinct step forward over previous books on the same subject and our only criticism is that, perhaps, the author did not go far enough.

It is for this reason particularly that we regard the author's choice of the time factor $e^{-i\omega t}$, instead of $e^{+i\omega t}$ generally used by engineers in this country, as highly regrettable. It will be a source of constant confusion to see the inductive reactance negative when it has become one's second nature to think of it as positive. In this departure from conventions, the author was motivated by a desire to use a positive exponent in the expression e^{ikz} for a progressive wave moving in the positive direction; but, again, one has already developed a habit of associating e^{-ikz} with such a wave. It is to be hoped that the author will find it expedient to go back to well-established conventions at the earliest opportunity. In the meantime the readers must be prepared to replace all expressions in the book by their conjugates if they wish to see them in the conventional form.

There is another departure from the convention that the reader may wish to keep in mind. Engineers write the general exponential factor associated with a progressive wave moving in the direction of increasing co-ordinate x in the form $e^{-\Gamma x+i\omega t}$ and call $\Gamma=\alpha+i\beta$ the "propagation constant"; furthermore, they call the real part α the attenuation constant and the imaginary part β the phase constant. On the other hand, the author writes his factor in the form $e^{ikz-i\omega t}$ and calls $k=\alpha+i\beta$ the "propagation constant." Aside from the interchange of letters α and β, the engineer would call k the "complex phase constant" if he wished to talk about it at all. The conventional propagation constant Γ is connected with the author's propagation constant k by the equation $\Gamma=-ik$.

On page 602 the column headings "Multiply the M.K.S. unit below" and "to obtain the C.G.S. electromagnetic unit of" should be replaced respectively by "Multiply the number of the M.K.S. units below" and "To obtain the number of C.G.S. electromagnetic units of." Corresponding change should be made on page 603.

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Contributors

J. J. Adams

James J. Adams (A'36) was born on July 7, 1912 in Sioux Falls, South Dakota. He received a B.S. degree in electrical engineering from the University of Colorado in 1934 and the M.S. in electrical engineering from the same school in 1935. From 1936 to 1938 he was employed as a radio engineer with the Philco Radio and Television Corporation. Since 1939 he has been with the Zenith Radio Corporation.

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Ivan S. Coggeshall (A'26–M'29) was born at Newport, Rhode Island, on September 30, 1896, and attended Worcester Polytechnic Institute. Since 1917 he has been employed by the Western Union Telegraph Company in New York, having been appointed, in 1927, as general traffic supervisor of the company's submarine cable system. Mr. Coggeshall is a Lieutenant Commander in the United States Naval Reserve, and serves on the Cable Committee of the Defense Communications Board. He is a director of the Mexican Telegraph Company, a director of the Institute of Radio Engineers, and a member of Tau Beta Pi and the American Institute of Electrical Engineers.

I. S. Coggeshall

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Dudley E. Foster (A'26–M'37) was born at Newark, New Jersey on December 12, 1900. He was graduated from Cornell University in 1922 with the E.E. degree. Following his graduation he became associated with the Electrical Alloy Company and Driver-Harris Company. In 1925 he joined the Malone-Lemmon Products Company and the next year became chief engineer of the Case Electric Company. Two years later that company was merged with the United States Radio and Television Company and soon thereafter Mr. Foster

Dudley E. Foster

was promoted to chief engineer. In 1933 he became chief radio engineer of the General Household Utilities Company and since 1934 he has been division engineer in the RCA License Laboratory. He is also a lecturer in television engineering in the Graduate School of Stevens Institute of Technology.

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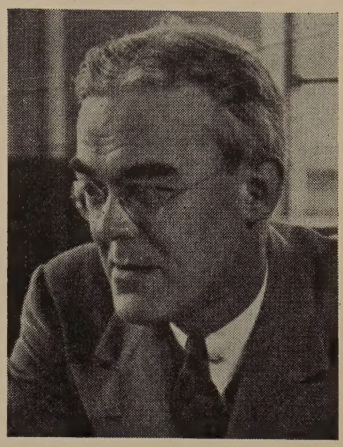
A. G. Jensen (A'23–M'26) received the E.E. degree from the Royal Technical College in Copenhagen in 1920, and remained there for a year as instructor before coming to the United States. During the winter of 1921–1922 he took postgraduate work at Columbia, and in the summer of the latter year joined what is now the research department of the Bell Telephone Laboratories. Until 1926 he was at the field laboratory at Cliffwood, New Jersey, engaged in radio receiving studies and in the design of field-strength-measuring sets. He then went to London to initiate short-wave reception from the United States, and remained there four years in charge of the test station during the development of transatlantic short-wave service. In 1930 he returned to this country to work on the development of the coaxial system, taking



A. G. Jensen

charge of the development of terminal and measuring equipment. Since 1938 he has been television research engineer in charge of experimental work on special television testing and terminal equipment.

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J. L. Jones (A'37) was born on July 24, 1909, at Fond du Lac, Wisconsin. He received the B.S. degree in electrical engineering from the University of Wisconsin in 1931. He was employed as research assistant by the Wisconsin Alumni Research Foundation between 1932 and 1934. In 1935 Mr. Jones became connected with the General Electric Company, and has been a member of the radio transmitter engineering department since 1938. He completed the General Electric advanced course in engineering and is a member of Tau Beta Pi, Sigma Xi, and Eta Kappa Nu.

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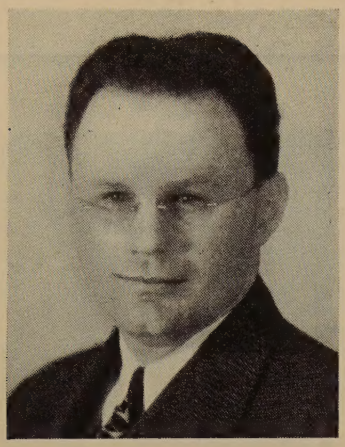
Arthur E. Newlon (A'38) was born at New Lexington, Ohio, on November 15, 1911. He received the degree of bachelor

J. L. Jones



ARTHUR E. NEWLON

of electrical engineering from Ohio State University in 1933. From 1933 to 1935 he was an assistant scientific aide with the United States Coast and Geodetic Survey working as a computor. He was engaged in development work on wired radio from 1935 to 1936 with the Muzak Corporation of Ohio. From 1936 to 1941 he served as an engineer with the RCA License Division Laboratory. Mr. Newlon is now a member of the research laboratory of the Stromberg-Carlson Telephone Manufacturing Company. He is a member of Eta Kappa Nu and Tau Beta Pi, and an associate member of Sigma Xi.

D. E. Norgaard (S'36–A'38) was born June 11, 1914. In 1936 he received the B.S. degree in electrical engineering from Rice Institute and joined the test department of the General Electric Company in Schenectady, N. Y. In 1937 he transferred to the general engineering laboratory of that company and was engaged in television development. Since 1938 he has been a member of the radio engineering department of the General Electric Company active in the development of television studio equipment. Mr. Norgaard is a member of Phi Beta Kappa and Tau Beta Pi.

D. E. NORGAARD

R. J. WISE

Raleigh J. Wise (M'40) was born at Hickory, North Carolina, on December 2, 1897. After receiving the degree of Electrical Engineer from the Georgia School of Technology in 1919, he entered the employ of the Western Union Telegraph Company, and for a number of years was engaged in the instruction of its technicians at Atlanta. In 1927 he was transferred to the engineering department in New York, and there has headed the group responsible for Western Union's facsimile telegraph and picture-transmission developments. Mr. Wise has contributed several inventions to the art, including the recording paper, Teledeltos, used in facsimile work.